DISCOVERY

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THE MAGAZINE OF SCIENTIFIC PROGRESS

JUNE 1961

31-

NEW RESEARCH TOOLS FOR THE ARCHAEOLOGIST

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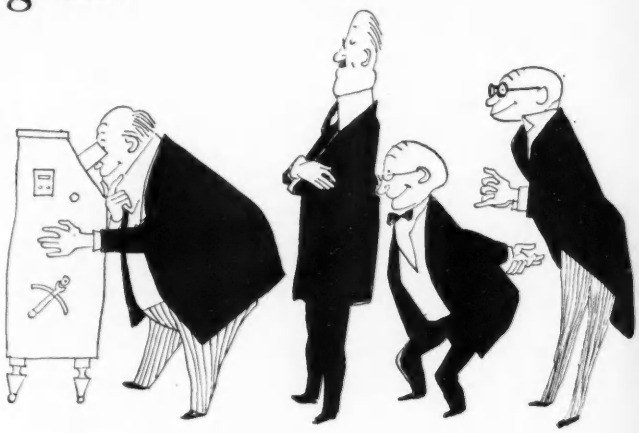

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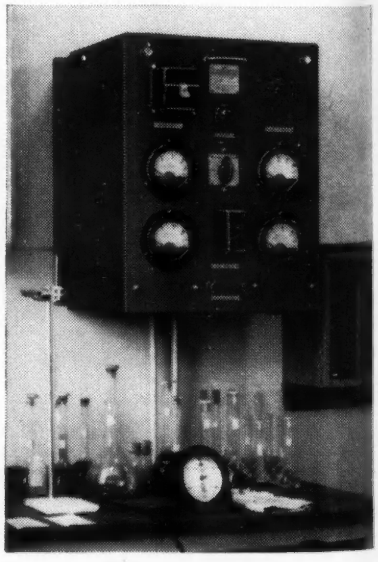

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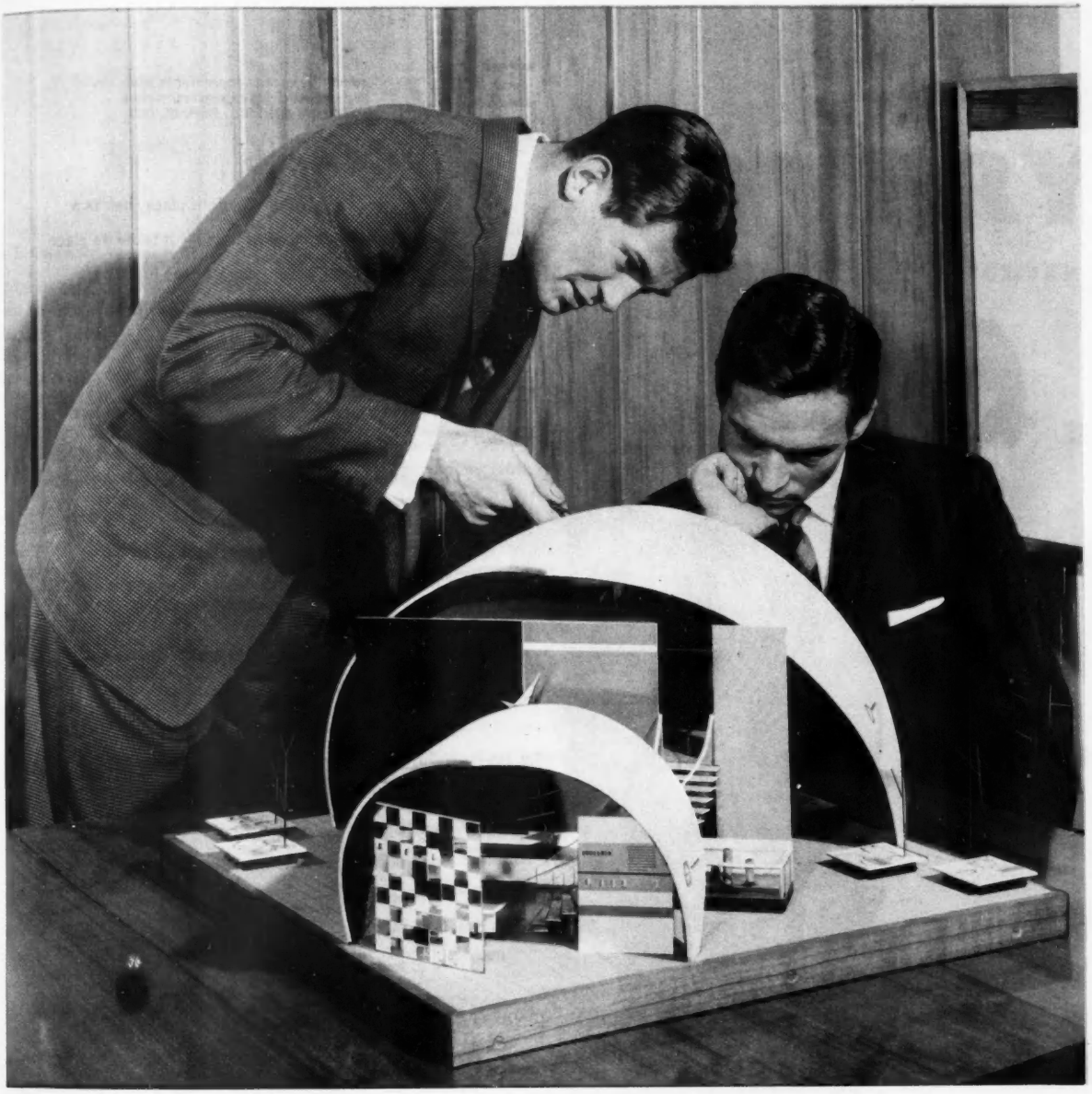

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Shell Chemicals SHELL

Hair

Admonui, ne trux caper iret in alas,
Neve forent duris aspera crura pilis
(Ovid, Ars Amatoria, Book iii, 193)

In its own way, and in the right place, hair is a thing of beauty, but scientifically it takes its place with wool, nail, hoof, beak, etc., as just one manifestation of keratin, a fibrous protein which exists in coiled (α) form and straightened (β) form, and exhibits unique elastic qualities.

Physiologically, as Wells has put it, a hair is a rod of dead cells proliferated by a living root. It is the result of a metabolism having as its end-product a coloured, self-lubricated, preferably curled fibre. The colouring material is melanin, and the lubricant is sebum. Because hair is an end-product, and because our ultimate interest in it is evocative, we can change its appearance and heighten its appeal without prejudice to its biological growth.

But whereas our knowledge of the structure of keratin is well-founded—due to the work of Astbury and Speakman in Leeds, Pauling in the U.S., and the C.S.I.R.O. team in Australia—and we have a reasonably clear picture of it in terms of stereochemical configuration, disulphide linkage and hydrogen bonding, the picture is not so clear when we think of keratin in terms of the cortex and cuticle of hair and the differences they exhibit in comparison with wool. Nor is the precise significance of sebum understood as a lubricant of the hair. At Unilever Research at Isleworth, therefore, Holmes and his colleagues are carrying out a programme of research on hair—its structure, its colour, its lubrication, and the influence of extraneous materials on them—to obtain a greater understanding of it.

UNILEVER RESEARCH

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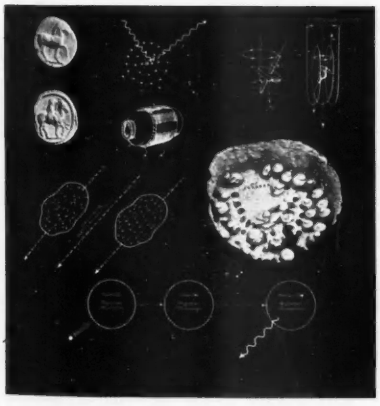
OUR COVER PICTURE



New research tools for the archaeologist

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THE PROGRESS OF SCIENCE

ELECTRICITY FROM THE DECOMPOSITION OF ORGANIC MATTER

A *biochemical* fuel cell developed by Dr F. D. Sisler, a biochemist of the U.S. Geological Survey, produces electricity directly from the decomposition of organic matter.

The development unit consists of an anode section and a cathode section that are separated by an ion-diffusion barrier. The anode section contains a mixture of sea water, organic matter and bacteria; the cathode section contains sea water and oxygen. When the bacteria "burn" the organic matter, energy is released as electricity.

According to a report in the U.S. journal *Missiles and Rockets*, scientists in the Geological Survey estimate the efficiency of the biochemical fuel cell to be equal to or higher than that of the most advanced types of conventional power plants (35–40%) and state that a much higher efficiency cell can probably be developed which could result in a revolutionary source of power for specialised and industrial use.

Sisler states that an inexpensive supply of both oxygen and organic fuel can be obtained by placing live algae in the cathode; the cell could then be made to produce electricity from solar energy alone.

DRIFT OF EARTH'S POLES

Recent analysis has shown a drift of about 15 cm./year in the mean position of the earth's poles of rotation, due to changes of position of either or both of the other sets of poles.

The earth actually has three sets of poles (apart from the magnetic poles): the rotation poles where the axis of rotation intersects the surface, the poles of figure which correspond to the axis of the maximum moment of inertia, and the geoidal poles which are defined by the bulge of the earth. Polar wandering—movement of the rotation poles—takes place whenever these three sets of poles do not coincide, a condition brought on by mountain building, erosion, and even by movements of large air masses and ocean currents.

Direct observation of the present rate of polar wandering is obscured by free nutation, or Chandler wobble, of the earth which results in a roughly circular motion of the whole planet about its rotation axis; the drift figure of 15 cm./year was arrived at by analysis.

Reductions in the Chandler motion seem to coincide with the occurrence of major earthquakes which may represent adjustments of the earth to polar wandering, and link this with mountain building.

DISPERSAL OF RADIOACTIVE TRITIUM FROM BOMB TESTS

A report on the dispersal of the tritium produced by the thermonuclear weapon tests of the United States and the Soviet Union was given by Dr W. F. Libby, the 1960 Nobel Prize winner in chemistry for his work on radiocarbon dating, at a symposium on the uses of tritium for hydrologic research at a recent meeting of the American Geophysical Union.

Libby stated that 43% of all the tritium produced has fallen out close to the test sites, 40% has fallen out elsewhere around the world, about 13% has disappeared through decay, and only 4% or so remains in the stratospheric reservoir. He described the extent to which the fall-out of tritium has proven useful in tracing moisture movements in the atmosphere, water movements in the oceans, and the movement of water through underground reservoirs. For example, it has confirmed the presence of a large area of upwelling—at least 75 miles in diameter—in the deep oceanic waters south of Santa Cruz Island, 100 miles off the California coast.

Dr C. W. Carlston, chairman of the symposium, pointed out that a very large part of the tritium that has come down has been promptly recirculated back into the atmosphere by evaporation and transpiration, and carried on to the ocean.

Carlston also reported that tritium analysis in a sand aquifer in New Jersey has made it possible to determine the amount of water that has been added to the ground water since the spring of 1954 (the date of the first thermonuclear tests, by the U.S.A.). Evidence was found of a hitherto undetected type of "flood"; it was discovered that excessive rainfall which produces a flood peak at the surface may also produce a secondary but greatly delayed and attenuated "flood" peak in the ground water reservoir. In the areas checked, the lag was thirty to forty-five days.

Two of the Hungarian stamps issued to celebrate the satellite flight of Yuri Gagarin on April 12. The U.S.S.R. has never published or released pictures of the actual rockets used to launch its satellites and space probes, but the rocket shown above has appeared a number of times in popularised accounts of the Soviet space programme and thus may bear some similarity to the actual rockets used.

THE DESIGN OF MAJOR GAGARIN'S SATELLITE

Official Russian reports on Major Yuri Gagarin's 108-min. trip round the world state that a pressure of one atmosphere and normal oxygen content were maintained in the satellite during the flight. The temperature was kept between 15° and 22°C by means of a liquid-gas cooling system that dissipated the internal heat to space by means of a radiator and system of shutters on the outside of the vehicle. The carbon dioxide content of the air was kept from going above 1% by the use of chemical compounds, and the relative humidity was maintained between 30 and 70%. A system of filters prevented the cumulative build-up of contaminants from the space-pilot's body and the equipment.

To properly orient the vehicle before the firing of the retro-rockets which started it on its way down—a critical operation that could lead to disaster if not done accurately—optical and gyroscopic sensors were employed with the sun as a reference point. The descent took about half an hour, during which the unit travelled more than 4900 miles.

The reports indicate it was also possible to orient the vehicle manually before the firing of the retro-rockets in the event the automatic system malfunctioned. The sensor to be used for this was an optical device in one of the portholes that would enable a fix on the horizon. It consisted of two annular mirror-reflectors, a light

filter, and a latticed glass. If the vehicle were properly oriented, light from the horizon would strike the first reflector, pass through the porthole, strike the second reflector, pass through the latticed glass, and produce a view of the horizon in the form of a circle. Through the central part of the porthole, the pilot would see the earth below and adjust the position of the ship's longitudinal axis by watching the "run" of the ground. It was presumably unnecessary to use the manual orientation system during Gagarin's flight on April 12.

A globe installed on the instrument panel made it possible to ascertain the vehicle's bearings during the flight and also predetermine the landing-point.

Allowances were made for the malfunctioning of several of the components, although none is known to have occurred. For example, the satellite was placed in a low orbit (a 112½-mile perigee and a 203-mile apogee) and the supplies and power sources were designed to last ten days; if the retro-rockets had failed, the ejection of a drag device could have brought the satellite back to earth in ten days or so. Second, Gagarin's space-suit could have been pressurised in the event of a leak in the pressurised cabin or a meteor hit. There was, in addition, a seat ejection arrangement which would have catapulted and parachuted Gagarin to safety if something went wrong during the launching or the final stage of the descent. The cabin also had two rapid-action hatches in the event the unit landed in water. To help locate him on landing, he was provided with pyrotechnical devices and radio means for communication and direction-finding; he also had an emergency store of food, water, and other equipment.

There was, fortunately, no major solar disturbance during Gagarin's flight. If there had been, he might have been seriously affected by a large dose of radiation.

EXISTENCE OF SOLAR WINDS CONFIRMED

Explorer X, the American space probe that was sent on a 145,000-mile up-and-down trip on March 25 to measure the magnetic fields in space, has confirmed the existence of "solar winds", a question that has been the subject of much controversy. These winds were found to be streams of protons, and speeds of about 900 miles/sec. were measured.

Correction

May issue, p. 207, Fig. 3. Last sentence of caption (*a*) should read: The curvature of space is positive so that the volume of space is finite.

Of the three instruments placed on board to measure magnetic field strength, the most sophisticated was a rubidium vapour magnetometer weighing only 1¼ lb. The rubidium atom rotates seven times a second in a weak magnetic field, but the spin increases with field strength, giving an accurate measure of its intensity.

Dr J. P. Heppner of the U.S. National Aeronautics and Space Administration said the findings indicate the winds are "fair to moderate" and "perhaps constant". He also reported that the measurements out to a distance of about 68,000 miles "give strong support to the theory that the interplanetary magnetic field in regions surrounding the earth is merely an extension of the magnetic field of the sun, this field being distended by solar winds.

The flight of *Explorer X* lasted about fifty-five hours. On March 27 it picked up the disturbance produced by the large solar flare that erupted the day before. The speed of the particles computed from the measurements was 3,260,000 miles/hr.

ELEMENT 103 CREATED AND IDENTIFIED

A team of scientists at the Lawrence Radiation Laboratory, operated for the Atomic Energy Commission by the University of California, have created and identified a new element, number 103 on the periodic table.

The Berkeley researchers have suggested the name "lawrencium" (chemical symbol, Lw) for the new element, in honour of the late Ernest O. Lawrence, Nobel prize winner, inventor of the cyclotron, and founder of the laboratory which now bears his name.

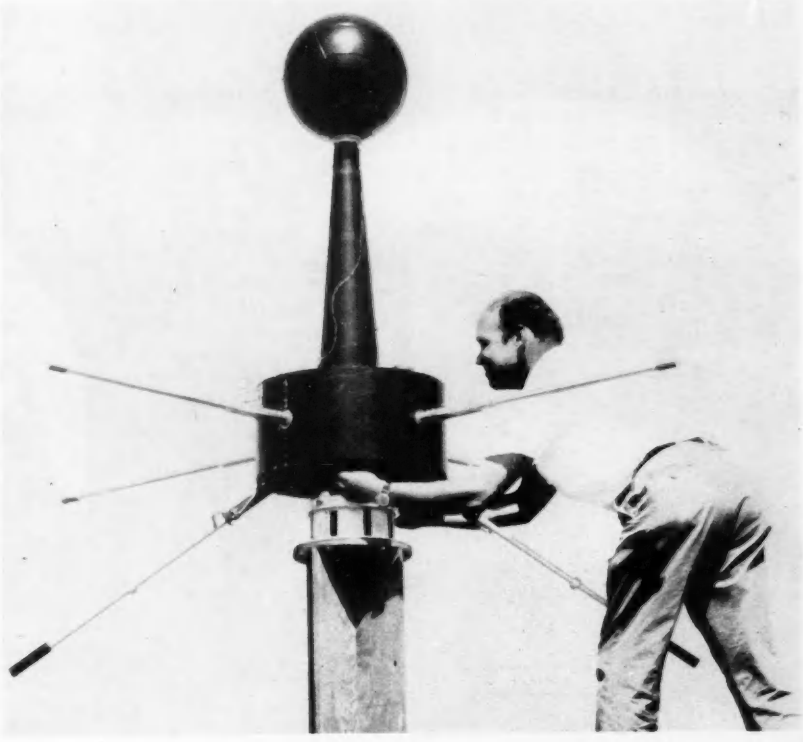
The discovery was made by nuclear chemists Albert Ghiorso, Torbjorn Sikkeland, Almon E. Larsh, and Robert M. Latimer, and is described in *Science*, the journal of the American Association for the Advancement of Science.

The scientists performed their experiments with the heavy-ion linear accelerator (HILAC), one of the major tools of nuclear research at the Lawrence laboratory.

The first evidence for the production of the element 103 isotope was achieved on February 14, 1961. Workers spent the next two months in confirming the February results. Attempts to produce element 103 span almost three years; the final six months were devoted to especially intensive experimentation.

continued on page 271

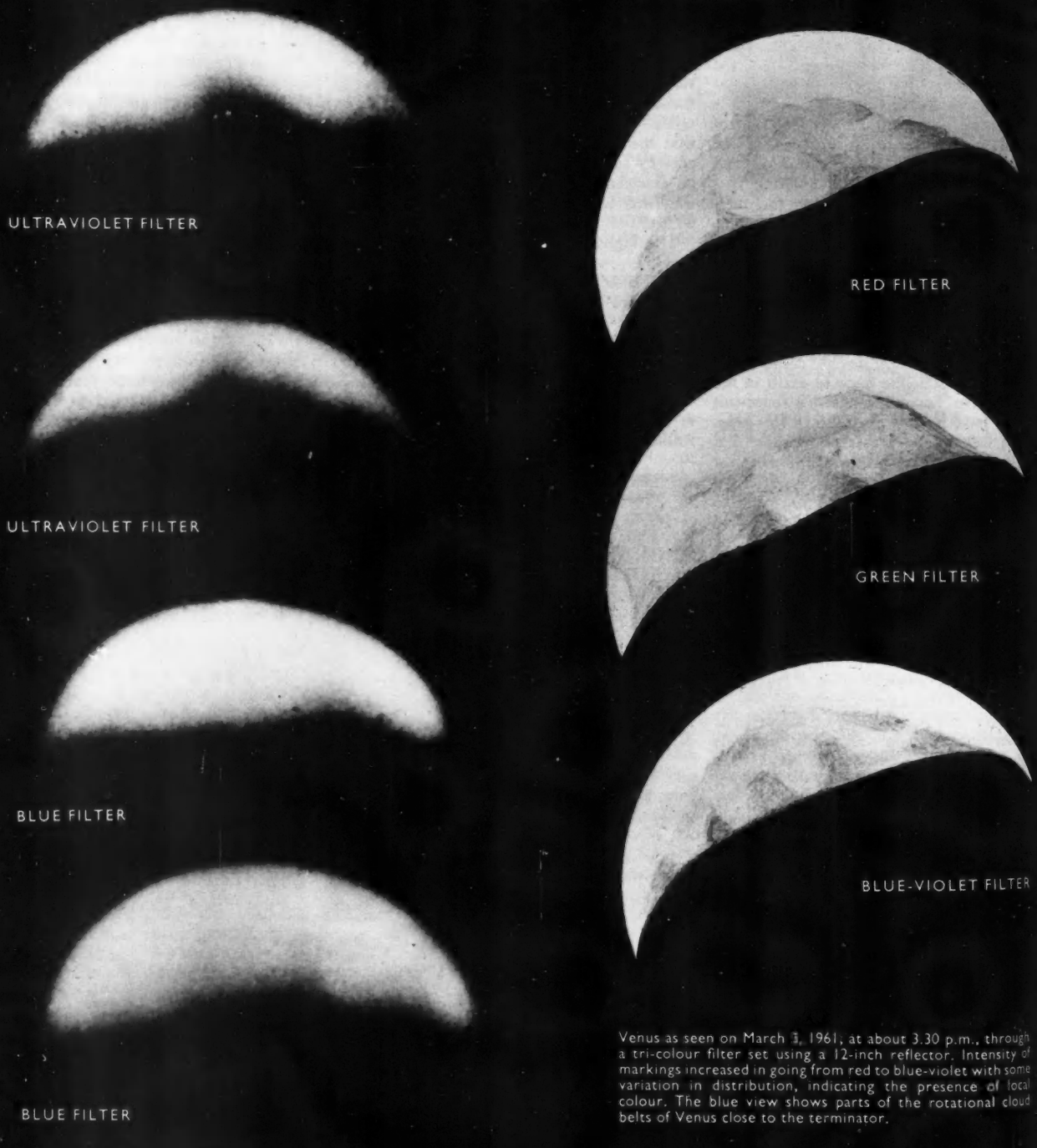
Explorer X, the American space probe that was sent on a 145,000-mile journey into space on March 25 to measure magnetic fields.



THE PLANET VENUS

Photographs taken with
100-inch telescope

Drawings by V. A. Firsoff



(Mt. Palomar and Wilson Observatories)

Venus as seen on March 3, 1961, at about 3.30 p.m., through a tri-colour filter set using a 12-inch reflector. Intensity of markings increased in going from red to blue-violet with some variation in distribution, indicating the presence of local colour. The blue view shows parts of the rotational cloud belts of Venus close to the terminator.

FIG. 1

VISUAL OBSERVATIONS OF THE PLANETS WITH COLOUR FILTERS

—ILLUSION AND REALITY—

V. A. FIRSOFF

Drawings of features on Mars, Venus and the other planets are far superior to photographs but there are many pitfalls. Most can be avoided by the use of colour filters.

The visual use of colour filters is now a well-established practice in planetary observation but it is still comparatively new and the question often asked is: What advantages has it to offer? Haven't colour filters been used for taking photographs of planets for at least fifty years? Is there any fundamental difference between the camera and the eye?

Although the sensitivity of the eye is not as good as that of the photographic plate, the eye has the advantage of ready accommodation to varying surface brightness. Because of atmospheric unsteadiness, planetary photographs have been greatly inferior in the presentation of surface detail to good drawings in which scattered moments of best seeing can be compounded (see Figs. 1 and 2).

There are some complications with visual observations, however. Quite apart from colour blindness and minor differences in colour perception between people with normal sight, the processes by which such perception is achieved are only imperfectly understood. Indeed, there exists no wholly satisfactory all-embracing theory of colour vision. The tri-colour response first proposed by Young and Helmholtz explains most fundamental facts but it does not account for the after-image effects and some other sensations of spurious colour.

When light of any colour reaches the eye, it leaves there a kind of transitory photograph which will persist from a fraction of a second if the light impulse is weak to several minutes if the light is strong and exposure prolonged, causing partial temporary blindness. (The latter can occur by looking at the Sun without a dark filter.) Such an after-image is complementary in colour to the incident light, but it alters colour as it fades; in fact, various colour sensations can be produced by rapidly moving black-and-white patterns. Some years ago Gehrcke obtained various colours by illuminating spinning cardboard tops, marked with black and white only, with the monochromatic yellow light of a sodium lamp. Fortunately, planets do not spin fast enough for such effects to concern the astronomer; his province is basically that of steady vision.

Yet even this is not all plain sailing.

Interesting experiments have recently been made by Dr Land in America. He used a red and a green filter to prepare black-and-white photographic transparencies of coloured objects and projected these transparencies coincidentally on to a white screen, the red-filter transparency with red light and the green-filter transparency with white light. The composite picture was not just red, black and white, as one might expect. Yellow, brown, green, and blue appeared as well, in close, though not perfect, agreement with the original colorations of the photographed objects.

Psychological factors may intervene in producing this illusion, and it has been suggested that two sets of nervous impulses may be involved. But, basically, this appears to be once more a matter of the after-image. Green-blue is complementary to spectrum red. The superimposition of red and green impulses yields yellow, and violet-blue is complementary to yellow. The eye is never quite still. It is moving all the time by small "saccadic" jerks so that the after-images of the highlights invade the neighbouring low-luminosity areas, imparting to these their own complementary colours which variously interact with the colours of the low-luminosity areas, if any.

The striking colours of many double stars arise in this way; if the brighter component is coloured it tends to impose its complementary colour on the fainter one. Similarly, in a reddish disc, any dark marking will *look*, but need not be, bluish-green. This has immediate relevance for Mars, whose dark coloured areas, or *maria*, appear bluish-green again, a generally reddish background. The real colour of the marking, however, is physically important and can be determined by means of filters.

ATMOSPHERIC ATTENUATION

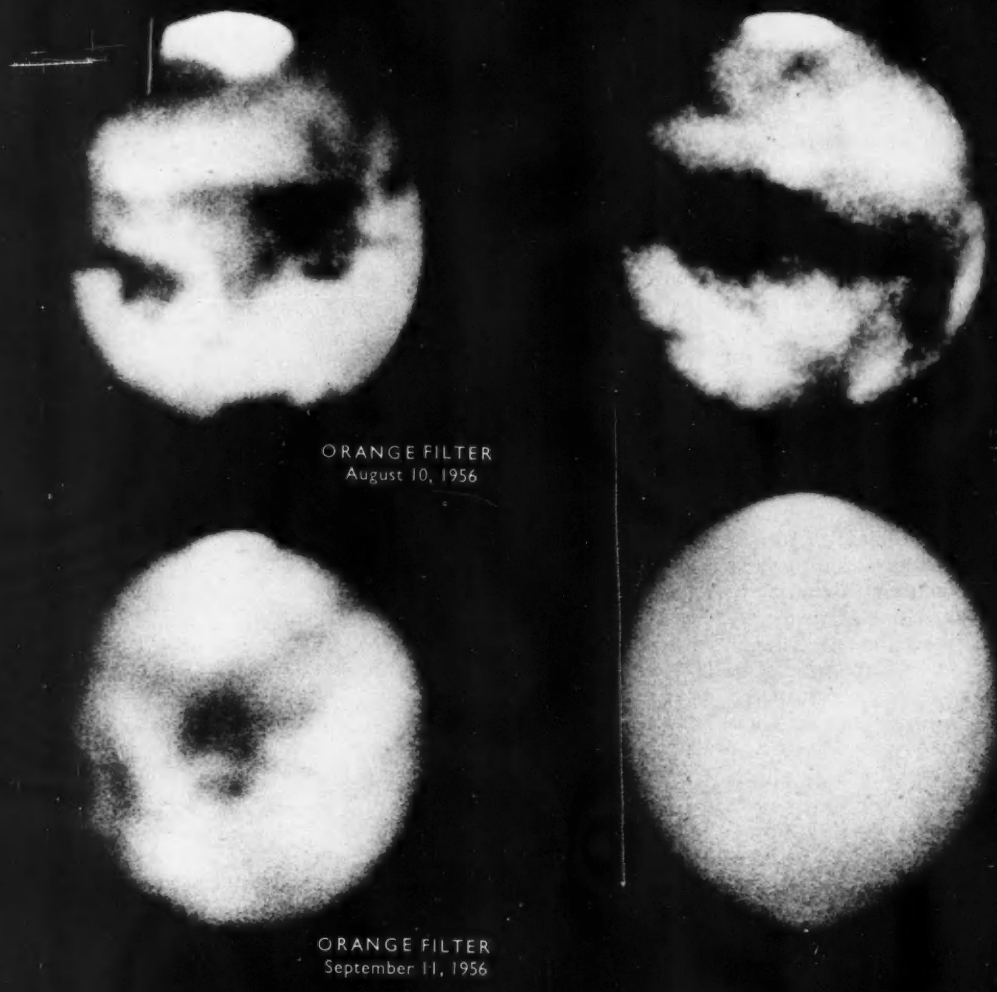
Apart from the illusory colourings due to after-image effects, the planetary astronomer has to contend with the attentuation of colour by the atmosphere.

Pure gases scatter light according to Rayleigh's Law; the scattering is inversely proportional to the fourth power of the wavelength and thus increases very rapidly with decreasing wavelengths. As a result, radiations of short wavelengths have little chance of penetrating a dense atmosphere. Yet even within the narrow optical range, the scattering and penetration vary considerably between the two ends of the spectrum. The light transmitted is "reddened", containing a larger proportion of radiation of the longer wavelengths at the red end of the spectrum than the incident light. The light reflected from a thin layer of pure gas will appear violet, becoming blue, greenish, yellowish, and finally white as the amount of gas along the line of sight increases. This process is well illustrated by the blue colouring of the sky at the zenith and its progressive paling towards the horizon. The red

V. A. Firsoff, M.A., F.R.A.S., M.B.A.A., is now engaged in research on planetary atmospheres and selenology and has written a number of scientific papers, articles and books on these and related subjects.

THE PLANET MARS

A Photographs taken with a 60-inch telescope during 1956



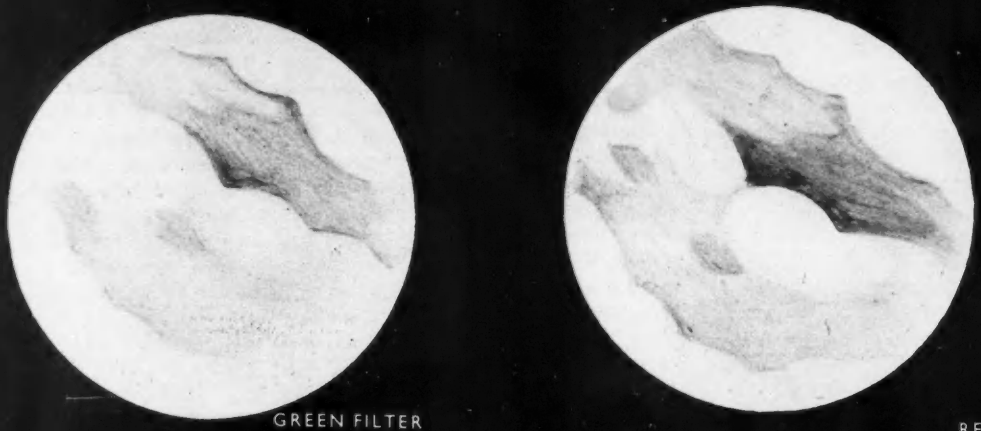
ORANGE FILTER
August 10, 1956

RED FILTER
August 22, 19

ORANGE FILTER
September 11, 1956

BLUE FILTER
September 11, 1

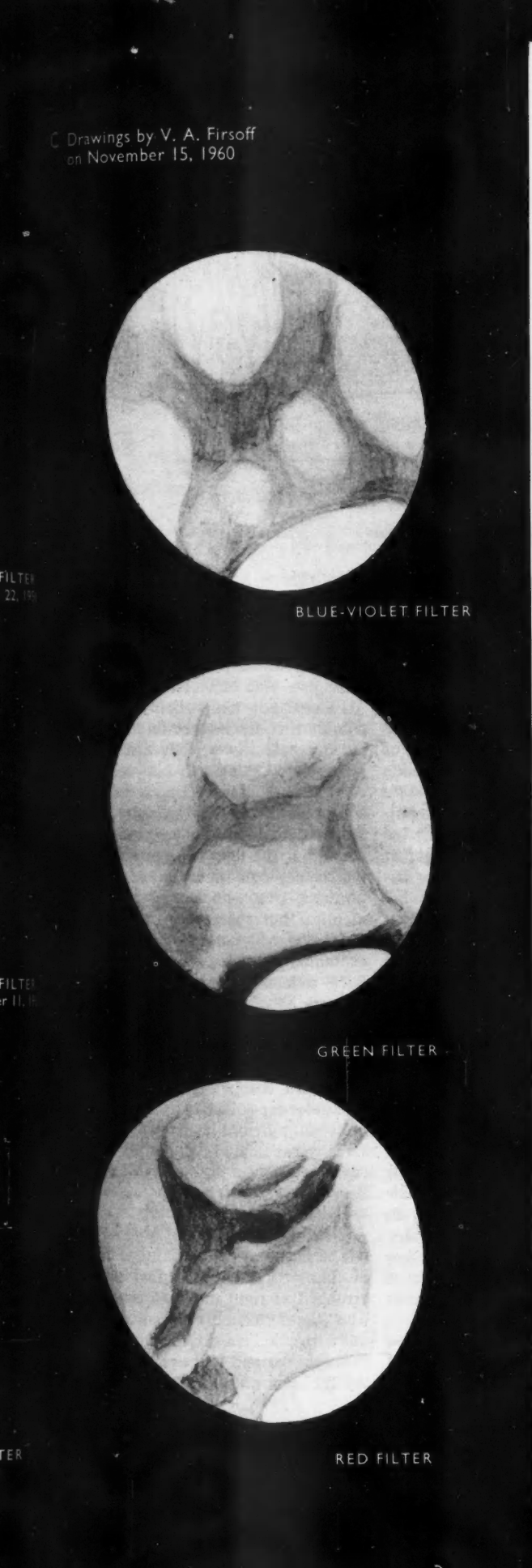
B Drawings by V. A. Firsoff on November 16, 1958



GREEN FILTER

RED FILTER

FIG. 2



colour of the rising or setting Sun is similarly due to the impoverishment of sunshine in shorter wavelengths.

These facts are well known and would hardly deserve mention, except for some of their less obvious implications. If compressed to the standard density (0° C and a pressure of 760 mm. Hg), the atmosphere of the Earth would be about five and a half miles thick. This is, therefore, the amount of air at ground density through which a heavenly body is seen at the zenith at sea-level. On a high mountain it will be appreciably less. On the other hand, planets are not generally to be looked for anywhere near the zenith, so that one must reckon with about ten miles of air at ground density in the line of sight. This makes a telescopic view of a planet or the Moon comparable to that of an Alpine peak ten miles away, which shows precious little colour. (The Earth's surface seen from the stratosphere appears grey-blue.) Only rarely does the colour come through to any great extent, and it is surprising how colourful even the notoriously colourless Moon can look sometimes.

Now, the Moon is airless to all intents and purposes, but the planets are surrounded by gaseous envelopes of their own which also cause colour attenuation.

Atmospheric attenuation is not an illusion; it cannot be eliminated by filters in the same way as spurious colourings arising from after-image or "contrast" effects, and it thus must be allowed for. Generally speaking, all dark markings will show the colour of the overlying gas and appear bluish, and all bright markings will appear reddish, or less blue. Sunlit grass on a distant mountainside may look pink on a hazy day; white clouds turn more or less yellow as they approach the horizon. And so, too, do the Moon and the planets.

The yellow colouring often observed in the clouds of Venus must be primarily atmospheric and at least some

FIG. 2. The Planet Mars as seen through colour filters.

A. Photographs taken with the 60-in. telescope at the Mt Wilson and Palomar Observatories during 1956. Upper two views are opposite hemispheres of Mars as seen through orange and red filters. Lower two were taken during September 1956, when haze in the Martian atmosphere obscured surface detail. The haze was partially transparent to the light in the pass band of the orange filter.

B. Drawings made on November 16, 1958, of the Mare Sirenum region (the planet rotates once every 24·62 hrs), using green and red filters. In accordance with the usual astronomical convention, south is at the top. Very little variation could be seen in the intensity of Mare Sirenum itself except for its northern part. The features farther north were greatly strengthened in red, indicating a strong green component in their colouring.

C. Drawings made on November 15, 1960, of the region of Syrtis Major, the filters revealing various colours and different atmospheric layers. Little of the surface detail showed with the blue-violet filter, but areas of cloud and haze were thrown into prominence; the polar cap was much enhanced, showing it to be covered by an icy haze. The green filter showed the Syrtis Major complex of markings faintly, indicating the presence of a strong green component, but there was a dark collar round the polar cap that must have been the complementary colour red, as indeed was evident in the red filter view where it was largely effaced. The red filter shows the *maria* clearly, both by reason of its haze-penetrating ability and the green in the *maria*.

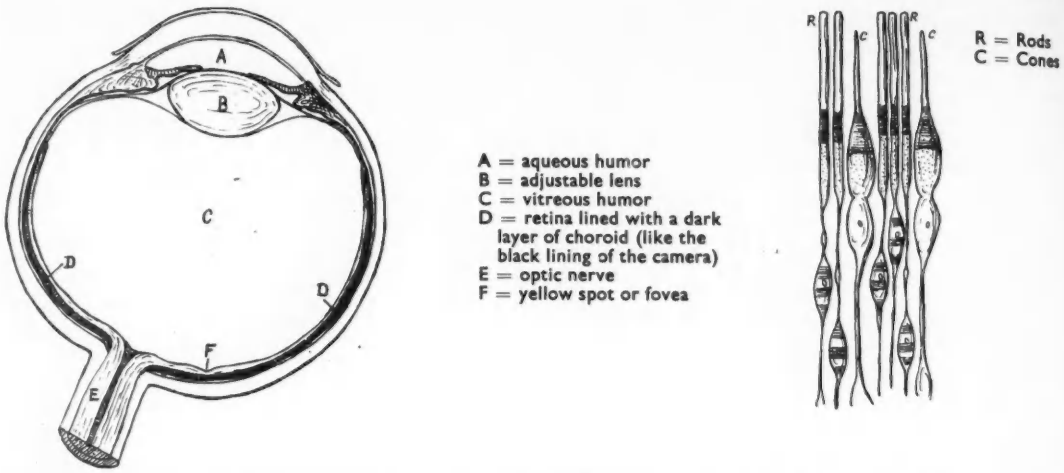


FIG. 3. (*Left*) Section through the human eye. (*Right*) Arrangement of rods and cones in a peripheral area of the human retina (greatly magnified).

of the apparent redness of Mars comes from the same source. Yet the belts of Jupiter look very dark through a blue filter, so that their colour cannot be due to ordinary atmospheric attenuation; when all due allowances have been made, there often is some residual colour which may be determined by means of filters.

It is an ill wind that blows nobody any good, however, and atmospheric attenuation does present one advantage. By means of filters different levels of reflection in an atmosphered body can be more or less isolated for study; the less refrangible the light used the deeper will the eye penetrate, and blue and violet filters may disclose delicate atmospheric veils which are inaccessible to the unaided gaze.

THE PROCESS OF ELIMINATION

The effects described above do not exhaust the list of colour pitfalls with which the visual observer is beset, quite apart from any chromatic errors of the optical system used.

The eye is not equally responsive to all colours and at all times. The light-adapted eye has its maximum sensitivity in the yellow-green part of the spectrum where the spectrum of solar emission reaches its peak, while the dark-adapted eye reacts more strongly to the more energetic quanta of shorter wavelengths. At dusk, all blue and violet flowers brighten up while the bright poppies in the cornfield turn black; a blue penny stamp is paler to the dark-adapted eye than an orange ha'penny one. This is the well-known Purkinje effect. Colour filters eliminate any errors that might arise from it, however. Although a blue image will appear brighter to the dark-adapted eye than a red one, filters enable a comparison of the relative intensities of their parts; the comparison is made within the same colour.

The unaided eye has further handicaps to overcome. If a mosaic of different colours—all equally bright at close quarters—is viewed from a distance, the light-adapted eye will be able to pick out only the red and the green-blue; all other colours will look grey. This is why red and green-blue are used for traffic lights.

But a monochromatic filter will show intensities of a single colour. Looking at objects through a yellow filter, all yellow or brown (dark-yellow) elements will be the brightest; red and green ones, which will contain some yellow, will look grey, and blue and violet ones will look black. If a blue filter is used, the situation will be reversed. In this way, the invisible colours of the mosaic can be established by comparing its appearance through different filters. Owing to the triple nature of colour vision, of which more will be said later, all colours can be determined by means of red, green, and blue filters.

Let us take another example. Narrow blue and yellow stripes, seen from a distance, merge together into a uniform white. Through a blue or yellow filter, however, the stripes of the other colour appear black. This particular point is of relevance to observations of Venus, which shows dark markings when seen through a blue or violet filter.

Filters not only help bring out colours that are inaccessible to the unaided eye, however; they also make it possible to distinguish between different whites or greys. (Grey is, of course, a comparatively low-intensity white.) Since white light can be produced by combining the light from any two complementary colours in the correct proportions, two whites may be visually identical but spectrally different. This difference will emerge when they are examined through a set of colour filters. Such differences may give important indications of the true nature of the substance that produces a planetary marking.

For example, snow is brightest in green and comparatively dull in red. The polar caps of Mars at once brighten up when a green filter is used and conversely lose some of their lustre in the red; so, too, do the bright areas near the poles of Venus.

TRI-COLOUR RESPONSE

The retina of the human eye consists of closely packed cylindrical elements, arranged at right angles to its surface (see Fig. 3). Some of them look like and are called *rods*. Others are pointed at the upper end and are called *cones*. At the centre of the yellow spot or

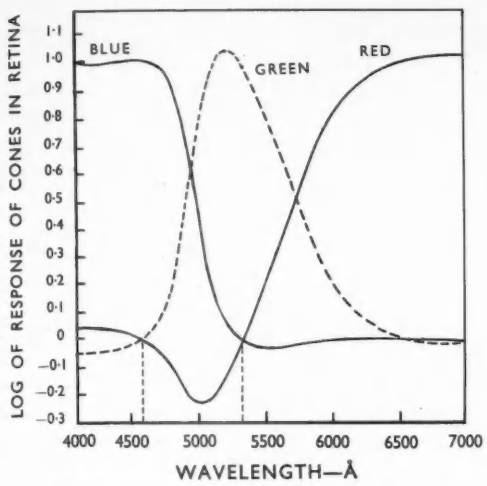


FIG. 4. Response of the three different types of cones in the human retina to different wavelengths of light (after Pirenne)

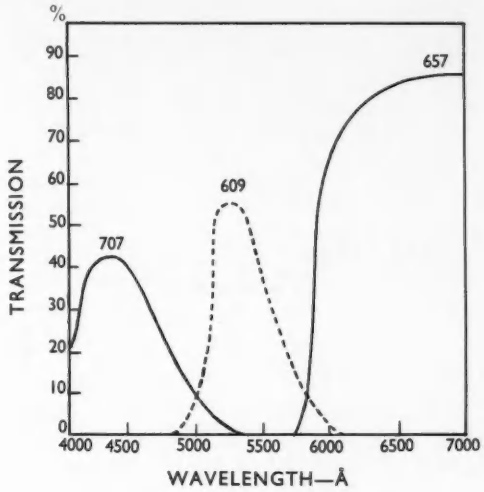


FIG. 5. Transmission characteristics of Dufay tri-colour filter set.

fovea, where vision attains its maximum acuity, there are no rods at all—only cones; at the periphery of the retina there are no cones—only rods.

These light-sensitive elements have different functions. The cones are connected to the optic nerve individually and the cross-sections they offer to the incident light are small. Hence their sensitivity is comparatively low but their resolving power is relatively high. Foveal cones have in yellow-green light a resolving power of about 2 min. of arc as against 10 min. for the rods, whose cross-section is larger and which are linked up with the optic nerve in groups.

The rods, however, are much more sensitive to the light of shorter wavelengths and, while their response to the red is approximately the same as that of the cones, their sensitivity in the blue is fully 10,000 times higher. In fact, 6 quanta of green-blue light, in which the peak sensitivity falls, suffice to actuate a rod. The energy is stored up over a short period until the threshold value is reached. This is why faint sources of light, such as stars in globular clusters and the minor satellites of the large planets appear to flash out intermittently. This is particularly noticeable in averted vision where the rod-rich peripheral portions of the retina are used.

The rods play little part in daylight vision but they go into action in the dark-adapted eye and the resulting shift of sensitivity accounts for the Purkinje effect. Night vision is colourless; to be exact, any faint light in the dark appears green, even a match struck in the distance. It is a point of some interest whether the rods respond to ultra-violet rays. In my experience they appear to do so; in certain circumstances I can see a little "lovat" glow beyond the violet end of the spectrum.

From the above it follows that colour sensations originate in the cones.

It is assumed in the tri-colour theory (which is wholly satisfactory for most purposes and is generally accepted, if not without reservations) that there are three kinds of cones with a maximum response in the red, green, and blue regions of the spectrum respectively. For the sake of brevity, they are referred to as red, green, and blue cones, though they are not actually so coloured. All colour sensations in a light-adapted eye are normally the result of the superposition of these three basic responses.

Fig. 4 shows, after Pirenne, the response of the three types of cones to different wavelengths of light in Ångströms. The scale of response is logarithmic for a definite reason, as we shall see later on.

Colour photography and television and tri-colour printing processes are based on this triple nature of colour vision. The various systems differ in some respects, however, because they have to work with materials which are not spectrally pure in colour. To illustrate: if yellow and blue pigments are mixed, whatever the proportion, the result is some shade of green and not white; this is also the result obtained if assorted blue and yellow lights are combined. This is due to the contamination of these pigments with green or, more precisely, to the fact that their reflection curves extend into the green region. As a result, the primary colours used for printing are peacock blue, magenta, and yellow, instead of the optical primaries—red, green, and blue —to which they are complementary. In all these processes, tri-colour separation filters are used.

For our purposes, only the sets of red, green, and blue need be considered. The spectral range of the filters differs somewhat in different makes. Such filters are not monochromatic; the red filter will transmit some yellow and so will the green, whose transmission will overlap to some extent with the range of the blue filter, the latter usually covering the violet part of the spectrum as well. The general idea, however, is to reproduce the tri-colour response of the cones in the eye; from the astronomical point of view, the closer the correspondence the better.

This is why I have found the Dufay tri-colour set particularly useful. Fig. 5 gives the transmission curves of these filters. The scale is different from that of Fig. 4 (the transmissivity being shown in percentages of the incident light and not logarithmically), but the resemblance between the two sets of curves is marked, even at first sight.

The Kodak "Wratten" filters have very similar transmission characteristics.

By using tri-colour filters to compare the intensities of the three basic colour responses of the cones in the retina to a given planetary marking, its true colour can be ascertained. Furthermore, the green filters eliminate the colour bias arising from atmospheric attenuation by suppressing the red and blue-violet light.

MONOCHROMATIC FILTERS

Broad-band monochromatic filters can be used for colour determination in the same way as tri-colour separation filters. Generally speaking, however, the procedure becomes more complicated with the increased number of filters and the loss of light means a large aperture and/or reduced magnification. Monochromatic filters may therefore be regarded as mainly ancillary to tri-colour separation filters; they are useful for checking up the colours of a feature as determined by tri-colour observation or for emphasising faintly coloured markings.

INSTRUMENTAL PROBLEMS

According to textbooks, the resolving power of a telescope is given by the formula

$$\delta = \frac{\lambda f}{a},$$

where δ is the minimum separable distance, λ the wavelength of the light, f the focal length of the objective, and a the diameter of the aperture.

This ideal, however, applies only to sharply contrasting markings in the absence of irradiation and in perfect seeing, so that it is not readily attained. Theoretical resolution cannot be improved by increasing magnification, but it is as well to bear in mind that the maximum green-light resolution at the fovea of the eye is barely 2 min. of arc. Thus it is not much use that the telescope can separate two stars if their images in the eyepiece are less than 2 min. of arc apart. Irradiation, too, has to be taken into account, so that the power of the eyepiece is by no means irrelevant for resolution, as is often erroneously stated.

It is, of course, true that at a certain point a loss of surface luminosity nullifies the advantages of increased diameter, but the eye has considerable powers of adaptation and a large disc is preferable for yet another reason.

According to Weber's approximate law (in Fechner's formulation), sensual response increases as the logarithm of the intensity of the stimulus. This is why cone responses in Fig. 4 are shown on a logarithmic scale.

The law is fairly accurate for visual perception, except for very faint and very strong stimuli outside the present scope of consideration. This means that the eye will distinguish small gradations in surface brightness much more readily in comparatively dim light than in strong light. The truth of this principle can be easily demonstrated by looking at a full Moon through filters of increasing density—it will be found that the *maria* become progressively darker. Excess of contrast with the sky background equally impairs the ability of the eye to see delicate shadings.

This point is of special relevance for Venus—an intrinsically brilliant object.

The optimum power to be used in any given conditions is a matter of compromise between the advantages of an increased image and the loss of light, which acquires particular importance with monochromatic filters. To some extent this is a matter of personal preference, but in my opinion most observers tend to use powers which are too low for planetary work, although they may be suitable for stellar observation.

PRACTICAL RESULTS

The drawings of Mars and Venus accompanying this article illustrate the results obtained by the visual use of colour filters. The successively executed sets of three drawings, using red, green, and blue tri-colour separation filters respectively, show the relative intensities of the planetary markings and their variation.

The Martian *maria* as a rule stand out most clearly through a red filter, which is to be expected because of atmospheric attenuation, the spurious blue tint imparted to all markings by the overlying gas, and the greater optical penetration of red light.

Large parts of the *maria* may also appear almost equally dark in green and red, and so must be a neutral grey. This appearance, however, does not usually extend to the whole disc, and other parts of the marial complexes are unequally emphasised by the two filters.

A blue filter discloses some of the atmospheric structure, often showing bright oval haze areas at the terminator, and enhanced polar caps. Another frequent appearance is that of dark and bright stripes, mostly three in number, ranged parallel to the equator. These stripes, or belts, were recorded photographically during the 1956 opposition, but they can often be seen quite easily if a blue-violet filter is used with a moderate aperture (6 to 10 in.).

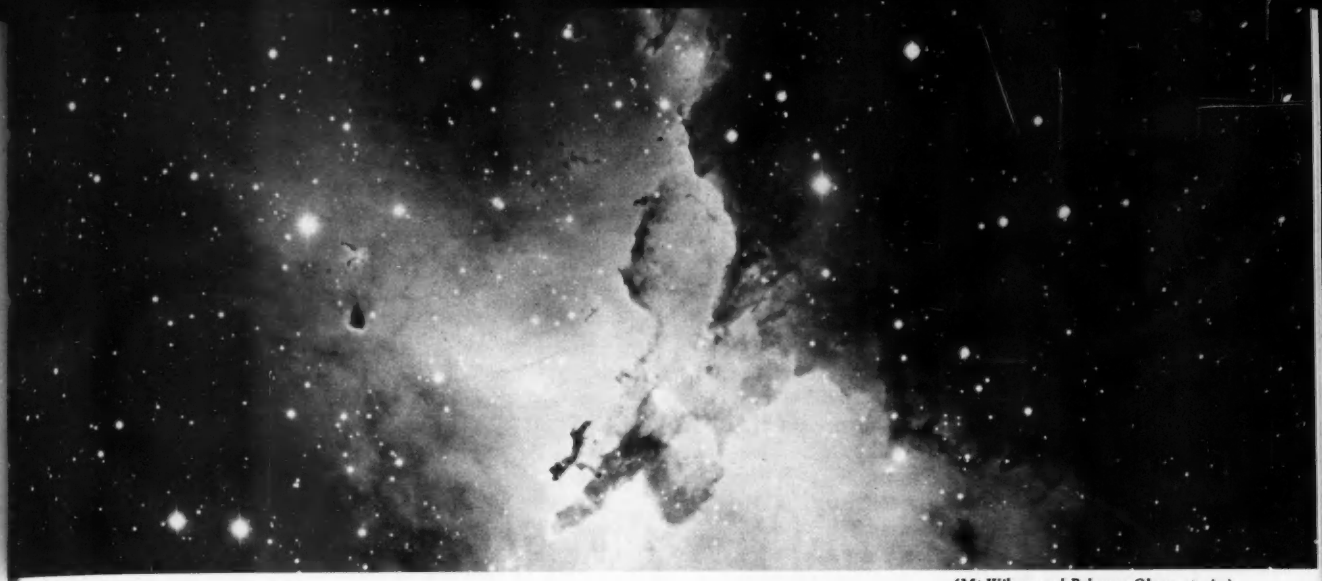
This belted haze in the atmosphere of Mars is the result of rotational deflection of the warm air streaming polewards from the equator and the cold air moving from the poles in the opposite direction and falling behind the linear speed of the underlying ground. The effect is also strongly marked in the atmosphere of Venus.

The belted structure can often be made out visually in all colours, but becomes progressively intensified from the red to the violent end of the spectrum.

Another interesting feature of Venus, especially marked if a green filter is used, is the bright oval (in perspective) areas which oscillate about the position of the cusps and agree with the inclination of the rotational belts.

The Moon has less colour and the effects revealed by filters are not so dramatic. Yet many dark areas in the lunar *maria* and craters show traces of colouring, usually green or violet, whilst red and yellow hues predominate elsewhere. Very few filter photographs of the Moon exist, but these colorations are clearly confirmed by the deep-red and ultra-violet exposures obtained by W. H. Wright and Dorothy Applegate at Lick way back in 1926!

Blue filters disclose interesting fluctuations in the brightness of some lunar craters and a dimming of stars at occultation has been observed by me in blue light. Oddly enough, nobody appears ever to have attempted to verify this effect.



(*Mt Wilson and Palomar Observatories*)

THE EVOLUTION OF "HUMANS" ON OTHER PLANETS

WILLIAM HOWELLS

One guess is that there are about a hundred million worlds where higher forms of life have actually been forged by evolution. Intelligent beings must abound in the universe, most of them far older than we ourselves. But what will they look like? Would "humans" evolve again on Earth if we wiped ourselves out?

The coming of Man on Earth has been extremely slow, his preparation long. We know, through millions of years, what powerful forces brought us out. We see what boons we have in skeletons, jaws, limbs, warm blood. Homely things, but with them any mammal is a testament of evolutionary creation. Add fingers and acute eyes, and you have something like a monkey. Add true hands and legs and you have the beginnings of a man. Then natural selection made our brains, and everything we do with them.

All this came gradually, in due course. Each patient step made possible the next. Each step gave rise to hundreds of kinds of successful animals, perfect in their own ways. Man himself could only appear when a very high organisation had been attained. For hands and a big brain would not have made a fish human; they would only have made a fish impossible. Man's own trail, among the many trails in evolution, was well defined: he had to be a mammal and he had to be a primate.

Was he inevitable? Mankind long thought so, and Genesis entertains no doubt that the world was made for us. Being human, we find it hard to see things any other way. Not long ago it was shocking to ask whether man had evolved from other animals. It is doubtless equally shocking to ask whether man arrived simply as a matter of luck.

Actually it would be a futile question. One cannot pass judgment on such a thing without going straight on to the origins of the universe. It does not matter here what your religious views are, for man must be looked on as an extraordinary achievement of design and organisation. The universe itself is built on laws of matter. These are the foundation for laws of life; and on such a basis, we know, man at last came on the scene. He was not there to begin with, and he took a long time coming. But he came, and he expresses all the fullness of the possibilities of the organisation of life as we understand it. How much of this is "chance"? There is no present answer.

I am not really trying to be profound, and I have little space here in any case. Talking about chance, I am merely wondering if man was forced to take the shape he did. If we had it to do over again, would we choose all the same forks in the road, or would we turn out differently? Perhaps science fiction has the answer.

Doubtless there are other "men" in space. Led by the astronomers, we now face possibilities of life elsewhere at which the mind boggles. We know there are many billions of stars in our own particular galaxy, the Milky Way. Galaxies like ours are grouped in clusters, thousands to a cluster, and such clusters go on and on, out of reach of the telescopes, by the hundreds of millions. Planets to live on? Dr Harlow Shapley has figured it out roughly.* Not many stars have planets around them, he thinks; perhaps one in a million. As in our own system, few planets are of the right kind, with water, days and nights, favourable temperature and chemicals, and so on. Perhaps one good place in about a

William Howells is Professor of Anthropology at Harvard University and a past president of the American Anthropological Association. This article is from his book, "Mankind in the Making", just published by Secker & Warburg.

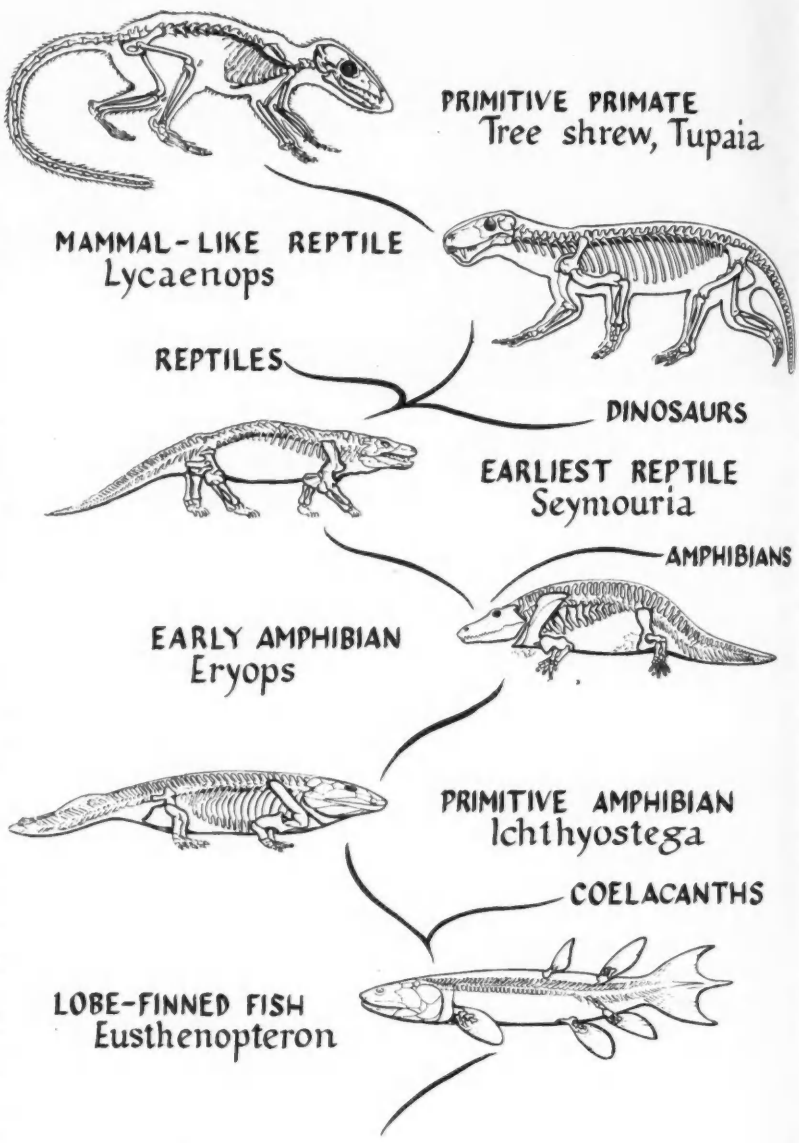
* In *The Atlantic*, November 1953.

trillion stars, all told. But these are really splendid odds, considering the number of stars; Dr Shapley ends by guessing that there are about a hundred million worlds where higher life has actually been forged by evolution. "We are not alone." Intelligent beings abound in the universe, most of them far older than we ourselves.

We can try to imagine what such people are like. Here we get little help from the comic books, which only show us flying saucers, manned by flabby little web-footed goblins with knobs on their heads. We must be strictly scientific, starting from scratch and assuming nothing about the beings we are studying, except that they are "intelligent". But this at once means that they are "human", in the sense that they have culture, like ourselves: they communicate ideas to one another, and create things jointly. Otherwise intelligence means nothing. And we could never communicate with them, if they could not already communicate with each other.

Furthermore, we might just as well imagine them on a favourable world something like ours, in matters of temperature, gravity, some atmosphere and land surface, and so on, since it seems to be the kind most suitable for life. Very well. We have intelligent, communicating creatures, on a far-away Earth. Are they anything like us? I think they are.

They might be considerably rearranged. They might "see" things we only "feel", like heat wavelengths; or "feel" things we "hear", and so on. Their "bones", or whatever props them up, might be differently placed in relation to blood vessels and nerves. But they would have these things. Communicating, creating creatures must have motion—they could not be like trees, with little power to act and exert force. So they would have to be self-contained, moving about and getting their fuel like the animals of this world. They would need structure, and a nervous organisation probably using electrical nerve impulses. They would need a liquid transportation system; we can hardly suppose that nourishment flows through their veins in the form of breakfast cereal. And so they must have begun their evolution, as we did ours, in a liquid medium, say water.



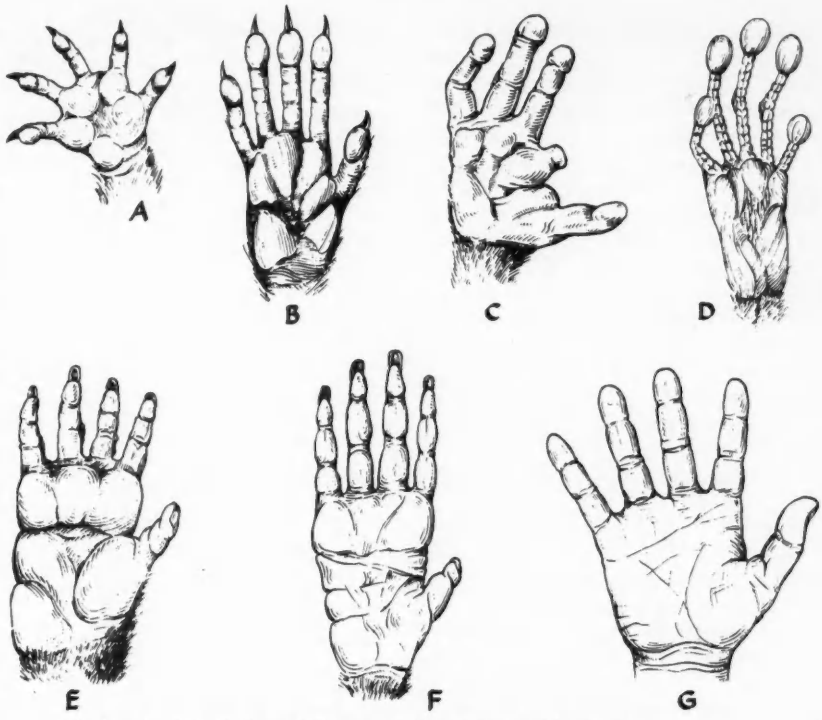
Will they be standing up and walking around like us? Might they not have two hands and four legs? Do we do anything well that a centaur could not do better? We go around on two legs because we had no other alternative if we wanted hands to use. The choice existed once, in the early fishes, but the lobe-fins and amphibians chose to keep only four limbs out of the original stock of fins. I will lay a small bet that the first men from Outer Space will have four legs and one pair of arms and hands.

(*Above*) Animals lying on, or close to, the line which led to man between fishes and mammals. (After Gregory, Jarvik, and Romer.)

(*Right*) Skeletons of forelimbs, showing adaptation to the different uses: (A) the proto-mammalian pattern in a mammal-like reptile; (B) a horse, highly modified by lengthening of the lower part and loss of separate forearm bones and of side toes; (C) man, with a general retention of the basic pattern. (Partly following Gregory.)

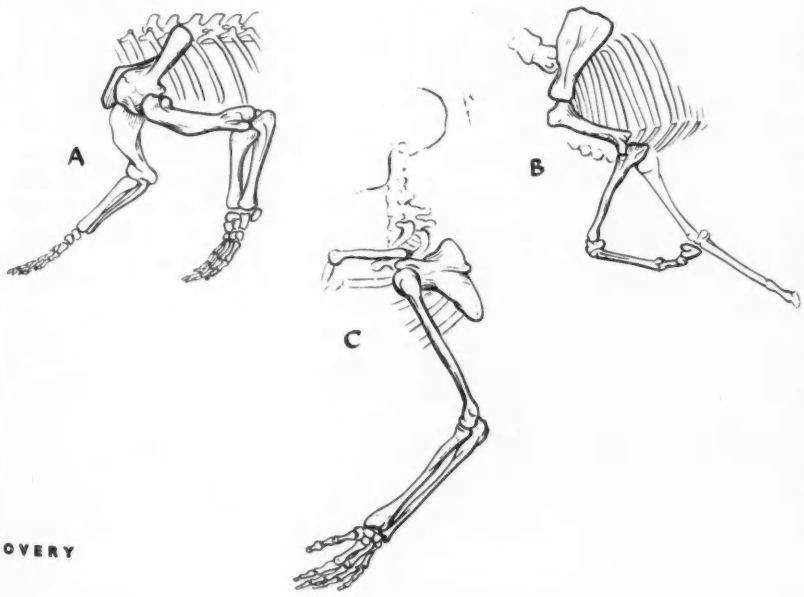
So much for raw material. What about design? Are the strangers round, or flat, or pointed? Do they smell through tail-fins and see through a radiator grill? The chances are excellent that they have a head end (which implies a tail end as well), because almost all the animals of this world which can move alertly and exert any real force are built on this same plan. It puts the senses where they will do the most good. And the main centre of the nervous system is close by, so that sense impulses will not have to make a long journey aft to a brain in the rump. Therefore our men will have heads. And, like the more efficient of our own animals, they will doubtless do their eating at this end as well. So, if they are going to be intelligent, our distant cousins had better be plotted something like a vertebrate or an insect of our own vicinity.

But they will do well not to imitate insects, for many reasons. All the co-operation of insect life—warrior ants, worker bees—is printed on the nervous system of each single insect. They act without benefit of ideas, only from instinct. Their social "ideas" come from natural selection alone, not from thought. So intelligent creatures will have made a choice, early in evolution, of a nervous system which is more open to fresh impressions: a brain which can learn. Eventually such a brain will become large. Come to think of it, it will make quite a lump somewhere, probably in the head.

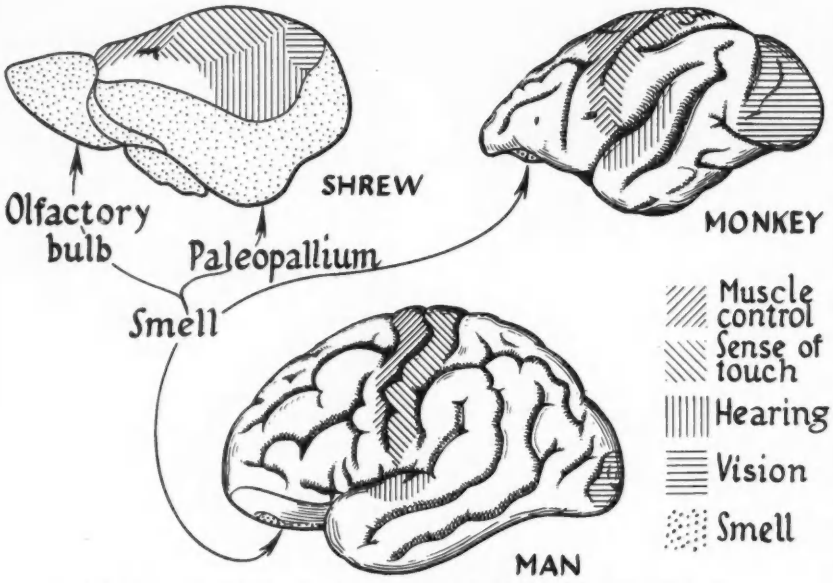


The hands will be better with fingers on them. There need not be five. Perhaps a few more or less will serve, but you may have been struck by the fact that we have decidedly kept all five of the bunch handed down to us by *Seymouria* and his forefathers. So five seems like a good number, perhaps a minimum. Therefore, look for plenty of fingers, on the ends of two arms. Two arms—not three—because the creatures should be symmetrical like us, and not four because co-ordination would probably be too difficult for efficiency.

(*Above*) Hands of (A) the opossum, primitive but mobile; (B) the tree shrew, with simple primate proportions; (C) the galago, using thumb and fourth digit for greater span, the second digit being reduced; (D) the *Tarsius*, a small hand with specialised enlarged skin pads; (E) the baboon, generalised in pattern; (F) the orang, lengthened for brachiating, with reduced thumb; and (G) man, with short fingers and long thumb for good opposition.



While we are roughing out shape, we might ask whether such a species will come in more than one form. Bees and ants do. And caterpillars turn into moths. Above all, the great majority of living things come in two sexes. It is one of nature's most popular ideas, and not for the first reason that will occur to you. Sex ensures a great plenitude of new gene combinations, different in each of the offspring, through the coming together of genes from two parents. This is one of the keystones of evolution, as you have seen. We on earth have long ago made all our arrangements on the basis of two sexes. Perhaps our extra-terrestrial equivalents have three sexes, like German nouns. Or more; who is to say? Certainly two is most likely. It is an almost universal rule here below, with no complaints.



Its brain—or whatever it operates on—must be absolutely large. There is no reason to suppose that the basic cells and fibres of the brain could be substantially smaller than the same things here, so there should be no saving of mass.

(*Above*) The cerebral cortex of some Earth mammals as seen from the left side (not drawn to scale). In a primitive mammal (insectivorous shrew, not to be confused with the primate tree shrew) most of the cortex is related to smell; the paleopallium is large and there is a prominent olfactory bulb in front to which the olfactory nerve leads from the nose. The neopallium (*above*) is still relatively small. In a monkey (macaque), the neopallium is greatly expanded, being all that is visible externally, and the olfactory areas are recessed under the forebrain. There are considerable association areas between those devoted to special senses. In man, the brain is larger still and highly convoluted. Association areas form a larger proportion of the cortex.

We now have a Thing with one head and two sexes. (Two heads are *not* better than one; making up a single mind is more than most of us can do, as it is.) We had better assume that It goes on land. The water is far less promising as a medium for creation and communication, though perhaps not impossible. As for air, the birds have found that it does not work out well, if the goal is intelligence. Birds are beautiful but stupid, having been obliged to put their brain development largely in the service of co-ordination of movement, for flying.

Being on land, these men will have limbs as well as a head. They must have limbs, because they must have hands. If we can learn anything from our evolution, it is that we had to be able to *do* things to become human. And our whole struggle was the getting and freeing of hands to do them with. Surely, we would not have had large brains without them.

The hands will be better with fingers on them. There need not be five; perhaps a few more or less will serve. But you may have been struck by the fact that we have decidedly kept all five of the bunch handed down to us by *Seymouria* and his forefathers. So five seems like a good number, perhaps a minimum. Therefore look for plenty of fingers, on the ends of two arms. Two arms; not three, because the creatures should be symmetrical like us; and not four, because co-ordination would probably be too difficult for efficiency. Centipedes have to run their arms in teams.

Now for a big question. Will They be standing up and walking around like us? They would not look very human otherwise. But might they not have two hands and *four* legs, that is, three pairs of limbs? Insects have. Do we do anything well that a centaur could not do better? We are reasonably content with our own seating arrangements, but perhaps we are making the best of a bad job. You know already why we go around on only two legs: if we wanted hands to use, we had no choice.

The choice existed once, in the early fishes. But the lobe-fins and amphibians chose to keep only four limbs out of an original larger stock of fins. Unimaginative beasts, what was good enough for a bedstead was good enough for a labyrinthodont. And so these feckless ancestors nearly slammed the door on hands entirely, since later hand-users (or wing-users) among the vertebrates had to manage by balancing on the two remaining legs. Supposing that ancient vertebrates had found some simple use for an extra pair of forelimbs, like the insects, while they still had the chance. Then these forelimbs might have continued being sufficiently adaptive for evolution to hang on to, as their possessors came out on land. Had this happened, we might all have avoided the problems which turn up in the blueprints of bipeds. There might, in fact, have appeared on earth many intelligent, hand-using, four-footed animals. So I will lay a small bet that the first men from Outer Space will be neither bipeds nor quadrupeds, but bimanous quadrupedal hexapods. (I have just invented that last word, in the hope that it means "six limbs".)

Finally, will they be big or small? Who will make a nice pet for whom, when we finally meet? Here, of course, gravity would keep weight down. But, on this earth at least, an intelligent animal must not be too small. Its brain—or whatever it operates on—must be absolutely large. And there is no reason to suppose that the basic cells and fibres of the brain could be substantially smaller than the same things here, so there should be no saving of mass. Furthermore, small animals—the active, highly organised kind, like mammals—do not live as long as large ones, not long enough to afford them the luxury of behaviour which is largely uninherited and must be learned very slowly. So other men should not be much less bulky than we are.

Perhaps they should be more so. We have not become bigger, ourselves, as we got brainier, and J. B. S. Haldane pointed out long ago the hazards of being too big. The giants in *Pilgrim's Progress*, or any story-book giants, were amateurishly engineered. Being the same shape as ourselves, they would have collapsed in a heap, with broken thighs; their legs were not big

enough to support their bulk. For, when an animal gets really large, its legs must become disproportionately thick and strong to keep up with its mass, its cubic content. This happens in elephants. Man, as a biped, is probably as big as is safe for him. Bipedal dinosaurs, it is true, got much larger, like *Tyrannosaurus*, but at the cost of being decidedly bottom-heavy, with great haunches and a fat tail. So the men of elsewhere, if bipeds, are probably no giants. But if they have four feet to hold them up, then they might well be as big as a horse, or larger, and still be both intelligent and manoeuvrable.

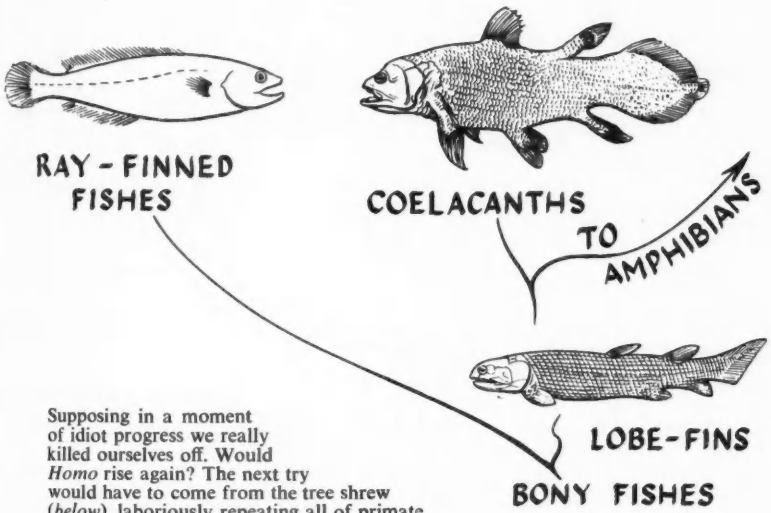
So, on the whole, perhaps mankind as represented by ourselves is a pretty good model for intelligent creatures. However, this does not tell us whether we had to happen at all. I have said what a "human" being might be like in other worlds than ours. But what about the chances of men coming into existence again, not elsewhere, but on this very planet? Supposing, in a moment of idiot progress, we really killed ourselves off. Would *Homo* rise again?

Man came from an australopithecine, or some simpler hominid, perhaps like *Oreopithecus*. Those animals are gone; man has competed them into the grave. There are still apes. They might do for a fresh start, but I strongly suspect they are too specialised, and too busy looking for fruit in the forest, to turn to freer use of hands. Monkeys? Just possibly, if something made it worth while for a species to stand up. The new men might then have tails. But, in fact, the monkeys have made no move to mimic the hominoids, or human ancestors, during about thirty-five million years.

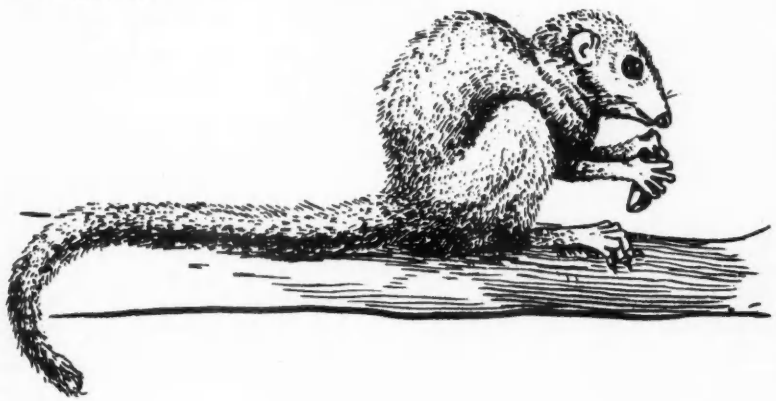
No other higher mammals of this earth will serve. Horses, dogs, elephants, all are deeply committed to being what they are. The next try would have to come from a tree shrew, laboriously repeating all of primate history. And before little *Tupaia* could put forth progressive descendants now, the world would have to be swept clean of the kind of competition which might overwhelm them on the way up. This means: get rid of most higher mammals, above all, rats, cats, and monkeys.

If he fails us, we (or rather our carbon copies) are done for. The remaining links of progress are now missing links; the good chances are gone. The mammal-like reptiles gave out long ago; and getting something human from the specialised creatures in the next ranks is hopeless: birds, snakes, frogs. The fishes? Lobe-fins, with the makings of lungs and limbs, were put out of business eons ago by the ray-fins, who can never leave the sea. The main army of fishes has gone well past the fork that once led to the land. Only the lungfish remain, waiting in mud for the rain to come again, and the coelacanth, so deep in the ocean that he dies in shallow water.

We might need brand-new "vertebrates". Well, then, eradicate the fish, who rule the seas as we rule the land and who are not likely to stand aside while nature experiments with ridiculously crude forerunners of ostracoderms once more. Conceivably life would have to start afresh. In that case, wipe out everything that moves, to keep the necessary simple molecules from being eaten as they form. So all in all our hopes for repetition are not good, and we had better stay the hand that drops the bomb.



Supposing in a moment of idiot progress we really killed ourselves off. Would *Homo* rise again? The next try would have to come from the tree shrew (*below*), laboriously repeating all of primate history. If he fails us, we (or rather our carbon copies) are done for. The remaining links of progress are now missing links; the good chances are gone. The mammal-like reptiles gave out long ago and getting something from the specialised creatures in the next ranks (birds, snakes, frogs) is hopeless. The fishes? Lobe-fins with the makings of lungs and limbs were put out of business eons ago by the ray-fins (*above*), who can never leave the sea. The main army of fishes has gone well past the fork that once led to the land. Only the lungfish remain, waiting in mud for the rain to come again, and the coelacanth, so deep in the ocean that he dies in shallow water.

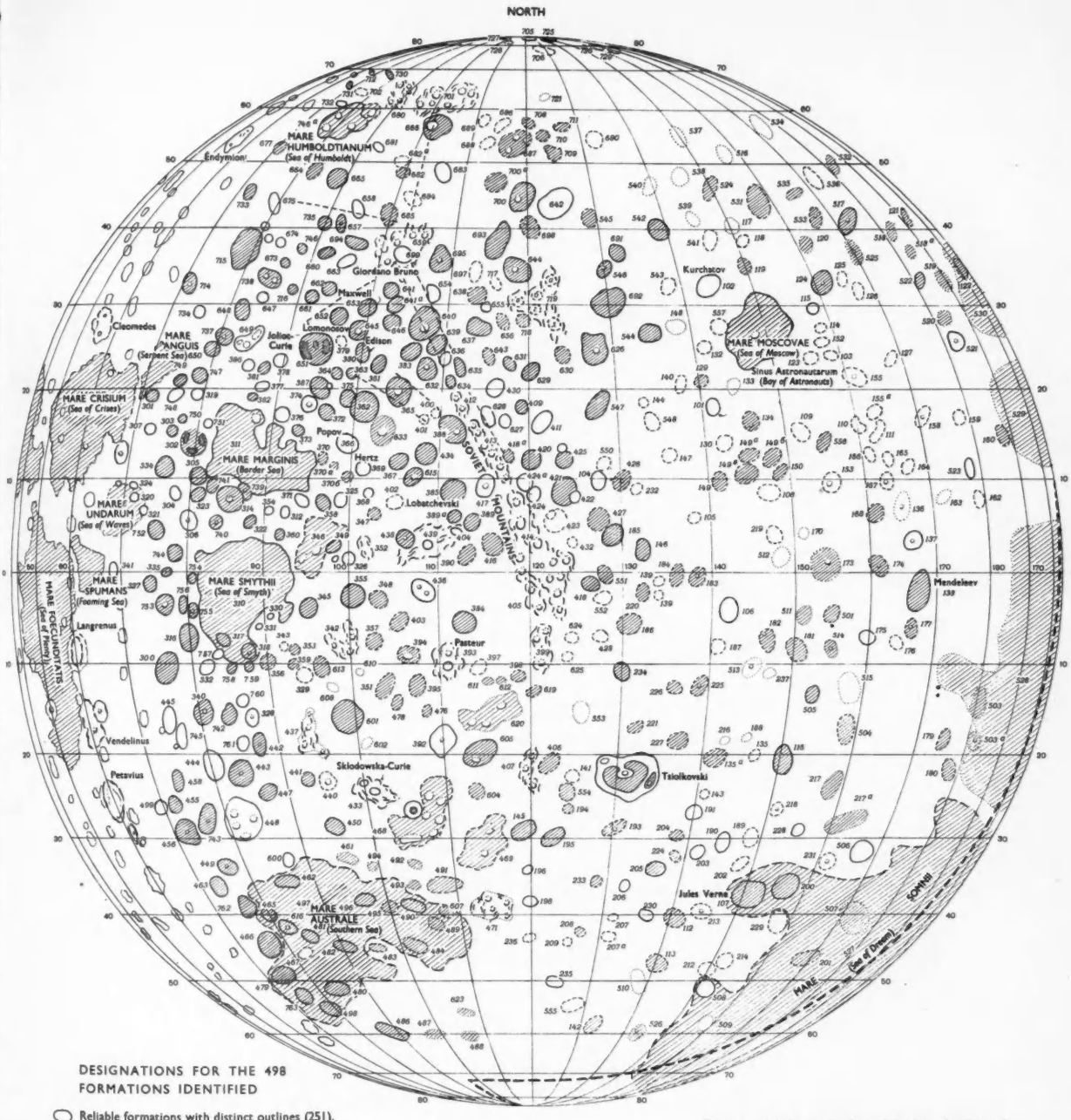


THE FAR SIDE OF THE MOON

The map and photographs shown here have just been published by the U.S.S.R. in its "Atlas of the Far Side of the Moon" The Atlas contains a total of thirty photographs taken with* Lunik III *plus descriptions of 498 lunar features that have been identified. All of the features are shown on the map, a distinction being made between the 251 that were reliably identified by at least three pictures and the others. About a hundred of those that were reliably identified are on parts of the Moon that are visible from Earth. Printed here are the forty-seven prominent features that have been listed by name in the Atlas with descriptions of how they appear in the* Lunik III *photographs. Thirty are located in the region of the Moon which is visible from the Earth; the other seventeen are new discoveries, most of which have been named after famous people.*

Number and name	Long.	Lat.	Description
101 *Tsu-Chun-chi*	141°	+18°	Stands out clearly in the photometric sections of a number of primary negatives as a bright formation on a grey background, of crater type. The wall is only outlined. The floor and the wall have almost the same brightness, but are considerably brighter than the surrounding surface.
102 *Kurchatov*	144°	+32°	Crater-like bright formation on a grey background. The wall is outlined more clearly from NW, and becomes less outstanding from the side of Mare Moscovae. It stands out well in many photometric sections.
107 *Jules Verne*	150°	−37°	A dark formation bounded by grey background. The floor is uniformly dark, the wall is slightly outlined. It is apparently a circular crater.
138 *Mendeleev*	167°	−3°	A dark ringed-plain type of formation. The wall is outlined, the floor is uniform. The surrounding surface is markedly brighter.
300 *La Peyrouse*	76°	−11°	A grey formation on a grey background. Of the crater type, bordered with a slightly noticeable wall. The floor is not uniform. It is felt that it comprises several craters. By position and size, it coincides with the La Peyrouse Crater.
302 *Lower*	79°	+14°	A dark formation on a grey background, bounded by unclear wall unnoticeable from the SW and N sides. Floor not uniform. There are apparently several dark craters inside, in the E, W, and S. By position and dimensions resembles closely the "Lower" crater.
307 *Alhazen*	73°	+15°	A grey formation on a slightly more grey background, apparently a crater. Bordered by a faint dark wall. By position and dimensions resembles the Crater Alhazen.
310 *Mare Smythii* (*Sea of Smyth*)	90°	0°	A dark formation on a bright background, in which isolated dark craters can be noticed. Contrary to the existing opinion that this mare is brighter than the maria Marginis, Spumans, and Undarum, it was found to be substantially darker when this photograph was taken. Its more accurately determined boundaries are: latitude +4°, −10°, longitude +82°, +94°. The contour is less tortuous than that of Mare Marginis.
311 *Mare Marginis* (*Border Sea*)	90°	+10°	A dark formation on a bright background, with a very tortuous contour. It is bounded by longitudes +82°, +96°, and by latitudes +8°, +18°. It apparently consists of a series of dark formations, of the type of craters with dark floors. The previously known contour was found to be inaccurate. It is obvious that the northern portion with the co-ordinates +83°, +88° of longitude, and +18°, +24° of latitude should not be included in the Mare Marginis. The same should be said with respect to the portion adjacent to Mare Marginis from the side of Mare Crisium and bounded by co-ordinates +76°, +81° (longitude) and +12°, +18° (latitude). This portion consists of single crater-like formations whose floors are brighter than the floor of Mare Marginis.
314 *Neper*	86°	+8°	A dark formation on a bright background, with a clear outline, bordered with a wall. The floor is not uniform. A peak in the centre. By position and dimensions it coincides with the Neper Crater.
316 *Kästner*	80°	−7°	A grey formation on a grey background, of the crater type, bordered with a wall which is brighter from the NE side. By position and dimensions it resembles the Kästner Crater.
340 *Behaim*	81°	−15°	The Behaim Crater is a grey formation on a bright background, bordered with a narrow dark wall. The floor is not uniform, and several craters can be noticed. The central part of the floor is brighter, and there is a central peak. By co-ordinates and dimensions it closely coincides with the picture of the Behaim Crater in the maps of Wilkins and of Neison.
341 *Maclaurin*	69°	0°	A bright formation on a grey background, of the crater type, bordered with a dark wall which is wider from the NE side. By dimensions it resembles the picture of the Maclaurin Crater in Wilkins's map, but it does not coincide by position with the Maclaurin Crater in Table XI of Wilkins's map.
366 *Popov*	99°	+14°	A bright formation on a grey background, of circular form, apparently a crater. N and S sides are bordered with a dark wall. The floor is not uniform, N part brighter than S part. Might consist of two contiguous craters.
369 *Hertz*	101°	+11°	A luminous formation on a grey background. Apparently a crater.
380 *Edison*	100°	+24°	A dark formation on a grey background, of the crater type. As regards brightness, the floor is intermediate between the details 645 and 651. Surrounded with a bright border from NE and N.
385 *Lobatchevsky*	112°	+9°	A dark formation on a bright background. Apparently a ringed plain. Bordered from W with a luminous background adjacent to the bright region 414.
393 *Pasteur*	111°	−10°	A luminous region on a grey background, bounded by the surrounding grey surface. According to one picture, it consists of round formations. One notices a narrow bright ring surrounding a round bright formation, and dark bands between them. By luminosity it resembles formation 439. Apparently consists of a number of single bright details.
414 *Soviet Mountains*	118° 124°	+9° −5°	These mountains present a luminous formation on grey background, consisting of a large number of single luminous details. The total outline is elongated and widens in the equatorial region. Its luminosity is more uniform in the N part; in the S part one notices single luminous details in high photometric sections. A darkening occurs in the SW part. Formation 413 is apparently also included in the Soviet Mountains.
433 *Sklodowska-Curie*	102°	−23°	A luminous formation on grey background with an indistinct outline. Because of its intensity, it stands out in most pictures. It apparently consists of very luminous single formations, almost merging with one another and presenting a mountainous formation.
442 *Raurich*	88°	−18°	A grey formation on a bright background, of the crater type, bordered from the N and NW with a dark wall which becomes barely noticeable on the S and SE. The floor is not uniform, brighter towards S. In the central part a luminous portion is noticed, apparently a peak. By position and dimensions, it resembles closely the Raurich Crater charted in Wilkins's map.
444 *Hekataeus*	81°	−21°	A grey formation on grey background, the type of crater with a non-uniform floor, bordered from W and E with a thin, narrow wall. In the N the outline is filled with interfering details. Single small craters are noticeable inside. By position it partly coincides with the Hekataeus Crater charted in the maps of Neison and Wilkins.

* Agent in Great Britain: Collet's Scientific Bookshop, 23 Museum Street, London W.C.1

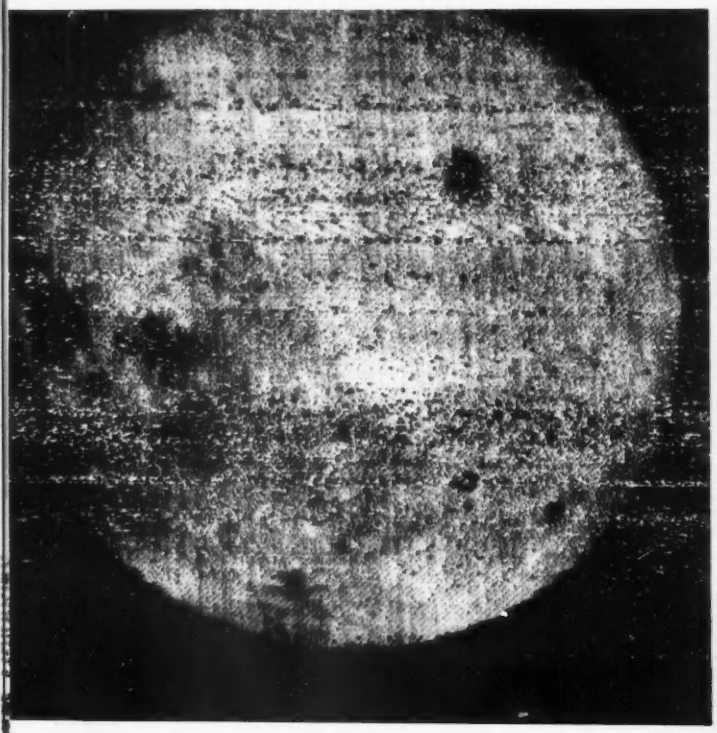


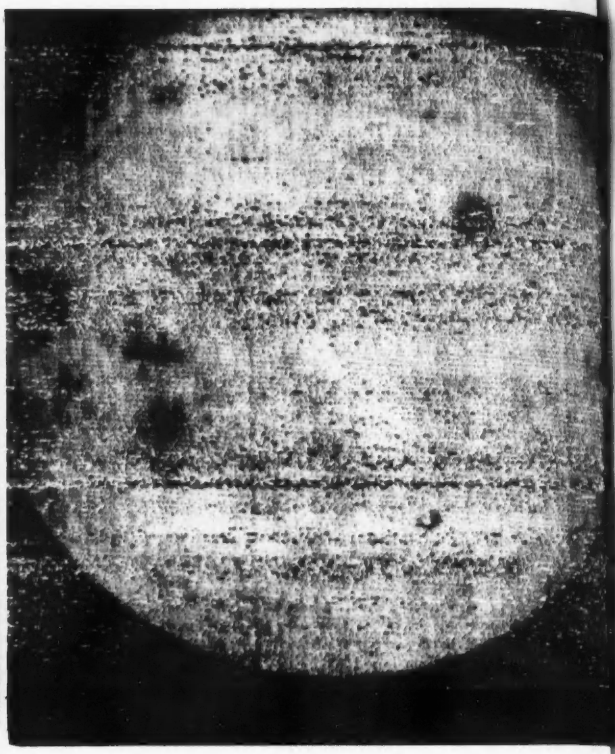
DESIGNATIONS FOR THE 498 FORMATIONS IDENTIFIED

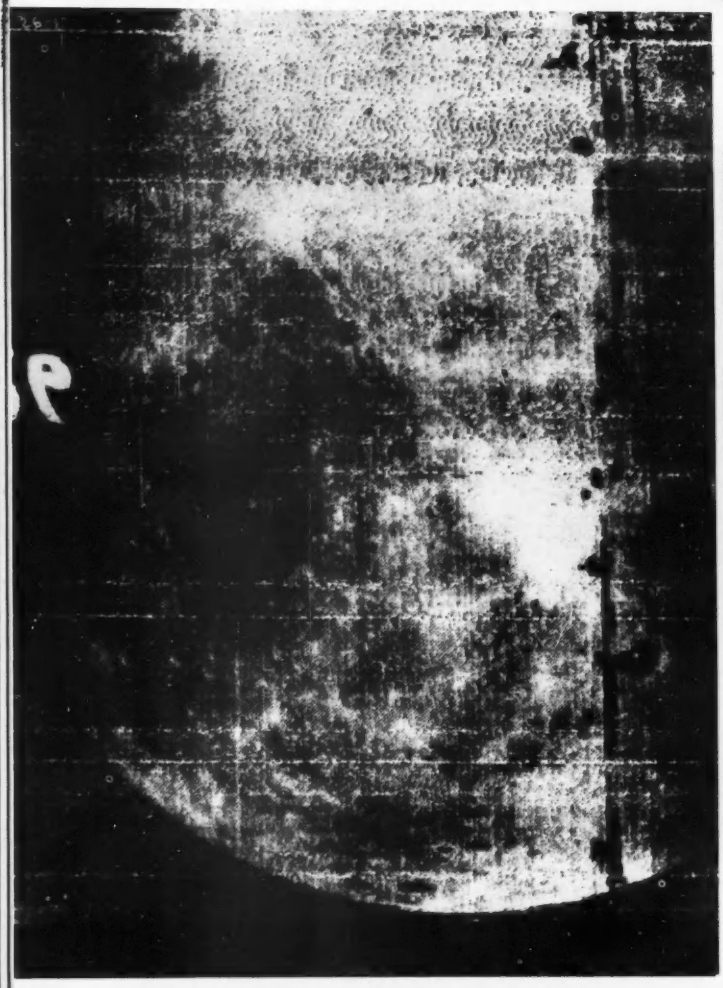
- Reliable formations with distinct outlines (251).
- Formations with less distinct outlines (190).
- Formations whose outlines require more accurate determination (57).
- Formations which are darker than the surrounding background.
- Formations which are brighter than the surrounding background.
- ---- Bright rays.
- --- Visibility limit.

Scale 1 : 10,000,000

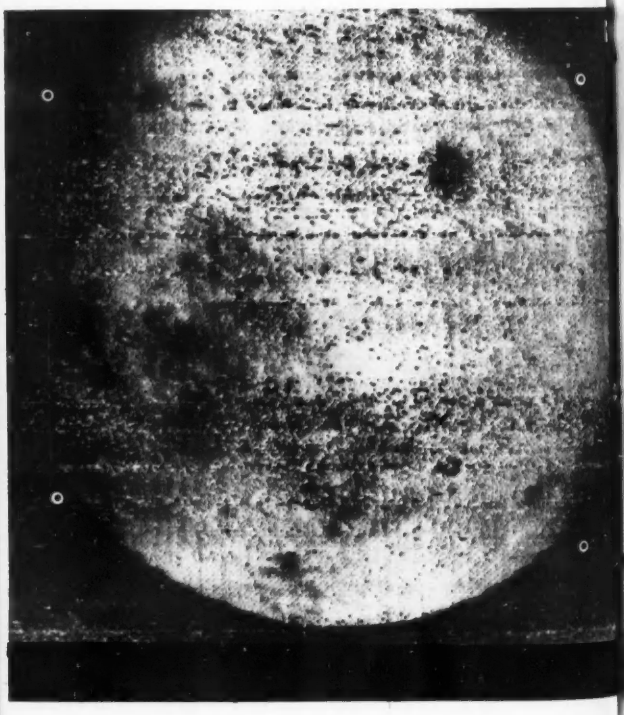
Drawn up jointly by the Central Institute for Scientific Research in Geodesy, Aerial Surveying and Cartography and the P. K. Sternberg State Astronomical Institute (all of the U.S.S.R.) on the basis of photographs taken from the Automatic Interplanetary Station on October 7th, 1959. The meridional zone between 30° and 70° of longitude is drawn up on the basis of maps of the visible side of the Moon.







Four of the thirty photographs published in the "Atlas of the Far Side of the Moon"



Number and name	Long.	Lat.	Description
448 *W. Humboldt*	82°	−28°	A grey formation on a dark background, bounded by a dark wall. Floor not uniform, differing little in brightness from the surrounding background. Small craters can be noticed on the floor. By position and dimensions closely resembles the W. Humboldt Crater charted in Wilkins's map.
456 *Legendre*	72°	−29°	A grey formation on a bright background, the type of crater with a non-uniform floor, bordered with a narrow bright wall from N side and with a wider bright wall from the S. Small craters are noticed on the wall from S, W, and N. A possible peak in the centre. By position and dimensions resembles the Legendre Crater.
466 *Oken*	77°	−44°	A grey formation on a bright background, crater type, bordered from SE with a thin, dark wall, brightens in NW and becomes hardly noticeable. Floor not uniform, dark towards SW. A peak is noticeable in NE. By position and dimensions resembles the Oken Crater.
497 *Mare Australe (Southern Sea)*	95°	−40°	A vast region with reduced reflective power; inside, a large number of craters with dark floors. From the observations of the libration zone it was bounded previously by −45°, −60° (latitude) and +74°, +90° (longitude). The more accurate form obtained from photographs yields the following bounding co-ordinates: −33°, −59° (latitude), +70°, +110° (longitude). The form is tortuous. The darkest portions are situated near longitude +90° and on either side of it. In the region −40° (latitude) and +95°, +110° (longitude), the reflective properties of the surface increase. Mare Australe is adjoined from N, W, and SW by portions of lunar surface characterised by a high coefficient of reflection.
527 *Mare Somnii (Sea of Dream)*	180°	−50°	Region of Mare Somnii stands out as a dark formation of elongated form on grey background. Here and there brighter than Mare Smythii and Mare Marginis. Apparently consists of a number of ringed plains and crater maria, such as the formations 107, 200, 507, etc. Mare Somnii adjoins directly a bright region consisting of formations of the type of 203, 180, 202, etc.
Tsiolkovski Crater	132°	−22°	A dark formation on grey background, crater type with a distinct broad wall; the wall is brighter from W. There is also a brighter portion in the NE part of the wall. Floor not uniform, relatively very dark; a distinct peak. The part between the peak and the N part of the wall is somewhat brighter than the surrounding floor and forms a slight ridge. A dark formation with a bright spot is seen in the SW part of the wall.
Mare Moscovae (Sea of Moscow)	149°	+27°	A dark formation of the mare type on a luminous background, with tortuous outline. The S part has a recess called the Sinus Astronautarum. Floor not uniform, with peaks here and there. Roughly in the centre is a luminous formation of the peak type. According to one picture, the brightness of the floor of Mare Moscovae is higher than that of Mare Smythii and Mare Marginis.
645 *Lomonosov*	99°	−27°	A dark formation on grey background, crater type, with intensely dark floor comparable to Mare Smythii. In one picture, bounded from NE and NW by a grey wall. The wall becomes indistinct in SE and SW. According to some pictures, one notices in the centre a peak which is absent in another picture.
648 *Seneca*	82°	+29°	A grey formation on bright background, crater type, with non-uniform floor which is darker towards SE. The NE part of the floor is brighter and differs but little from the adjacent surface. Bordered with a not very distinct dark wall which becomes bright from S side. By position and dimensions closely resembles the Seneca Crater.
651 *Joliot-Curie*	93°	+25°	A dark formation on grey background, crater type. Floor very non-uniform, darker from E and W sides, where dark spots are noticeable. Brightening is observed in the centre. A central peak is possible.
653 *Maxwell*	99°	+30°	A grey formation on a bright background, crater type, bordered with a brighter broad wall which becomes narrower in the S. Brightening of the floor is observed in the E part.
657 *Liddiard*	92°	+41°	A dark formation on grey background, crater type with shallow floor. In brightness it differs but little from the surrounding surface. The floor is darker in the N part. In the centre one sees distinctly a protuberance of the hump type, which stands out because of brightness. The presence of other small formations is observed. By co-ordinates it coincides closely with the Liddiard Crater.
665 *Polit*	88°	+48°	A grey formation of the crater type on a brighter background with a shallow floor which differs but little in brightness from the surrounding background. From NW side bounded by a bright wall which becomes darker in the SE. By co-ordinates and dimensions resembles closely the Polit Crater shown in Wilkins's map in the libration zone.
675 *Hallowes*	80°	+44°	A bright formation on a grey background, bordered from SE with a dark wall, and from NW with a thin line. One senses single luminous formations inside the crater. By co-ordinates it coincides with the Hallowes Crater, but in dimensions and orientation there is some difference.
699 *Giordano Bruno*	103°	+36°	A luminous formation. It might be either a very bright crater with a very high coefficient of reflection, or a mountainous portion. One of the brightest objects on the far side of the Moon. It is apparently the centre of a system of rays.
714 *Hahn*	72°	+32°	A grey formation on a bright background, crater type, bordered with a dark wall from SE and SW. The wall is brighter in NE and NW. Roughly in the centre one notices a luminous point, apparently the central peak. To the E the adjoining region is substantially darker compared with the part behind the W wall. By co-ordinates and configuration it coincides with the Hahn Crater.
715 *Gauss*	78°	+37°	A dark formation on a grey background, crater type. Floor of non-uniform brightness. There appear single small formations. The outlines are not distinct. From the N there adjoin directly two small craters. The length of the crater is nearly twice its width. By co-ordinates it closely coincides with the Gauss Crater in Wilkins's map.
735 *Palisa*	89°	+41°	A grey formation on a bright background—apparently a crater with a deepened floor which is darker in the S part. Surrounded by a bright wall which merges in the N with the surrounding surface with respect to brightness. By co-ordinates and configuration it coincides with the Palisa Crater found in Wilkins's map.
737 *Plutarch*	80°	+26°	A grey formation on a bright background, crater type, bordered with a weak bright wall which is more luminous from NW. The floor is not uniform, and a peak is possible in the centre. Stands out clearly in one picture which even shows two small craters situated on the S wall. Coincides closely by co-ordinates and dimensions with the Plutarch Crater.
738 *Timoleon*	85°	+34°	A grey formation on a bright background, crater type, with a non-uniform floor in which two small craters are noticeable. Bordered here and there with a discontinuous dark wall. From the N bounded by a broad, bright wall. By co-ordinates almost coincides with the Timoleon Crater in Wilkins's map.
743 *Phillips*	78°	−27°	A dark formation on a bright background, crater type, bordered from SE and NW with a dark wall, and from NE and N with a narrow bright wall. The floor is not uniform. There might be a central peak. Position and dimensions coincide with the Phillips Crater.
744 *Schubert*	78°	+2°	A grey formation on a bright background, crater type, bordered with a thin wall which becomes hardly noticeable in N and NE. Floor not uniform. Small craters might be present. By position and dimensions closely resembles the Schubert Crater shown in the maps of Wilkins and Neison.
746a *Mare Humboldtianum (Sea of Humboldt)*	80°	+57°	A dark formation on a bright background. Clearly bounded from NE, E, and SE. The opposite part of the outline is less clear. In the W part the floor becomes brighter approaching gradually the brightness of the background. One notices on the floor a number of craters which are darker in the E part. As could be expected, the outline does not coincide with that adopted on maps, especially in the W part.
762 *Marinus*	77°	−39°	A grey formation on a bright background, bordered from NW and SE with a dark wall. In NE the outline is not clear. By position and dimensions resembles closely the Marinus Crater.
763 *Hanno*	75°	−54°	A dark formation on a grey background, crater type with a dark floor. By position and dimensions closely resembles the Hanno Crater shown in the maps of Wilkins and Neison.

NEW RESEARCH TOOLS FOR THE ARCHAEOLOGIST

M. J. AITKEN

A variety of recently developed techniques now make it easier to locate the remains of ancient civilisations and determine their age. Non-destructive analytical methods just developed are also throwing new light on these civilisations by making it possible to trace the sources of origin of the raw materials they used.

The development of new techniques for locating, analysing, and dating ancient artifacts has had a revolutionary impact on prehistoric archaeology. The immutable decay of the radioactive carbon once absorbed by living organisms has at last provided an absolute time scale, and the more recent techniques of magnetic dating, thermoluminescent dating, and layer counting have put additional age-measuring tools in the hands of investigators. In addition, the proton magnetometer has made it possible to locate buried sites quickly, and chemical analyses can now be made with neutrons and x-rays without destroying specimens that are often irreplaceable.

RADIOCARBON DATING

Radiocarbon dating stems from the research done by W. F. Libby[1] on the fate of the neutrons produced by cosmic rays in the upper atmosphere. Few cosmic-ray neutrons reach the surface of the earth and Libby concluded from a study of laboratory experiments with neutrons that nearly all of the neutrons produced by cosmic rays would end their lives by interacting with atmospheric nitrogen (N^{14}), transmuting it to carbon-14, a weakly radioactive isotope of ordinary carbon (C^{12}), as depicted in Fig. 1. The resulting "heavy" carbon dioxide mixes in with the ordinary carbon dioxide of the atmosphere and its subsequent behaviour is indistinguishable except that the carbon-14 nuclei occasionally emit a beta particle, thereby transmuting back to nitrogen-14; the process is slow and on the average it will take eighty years for 1% of the initial carbon-14 nuclei to decay. Since atmospheric carbon dioxide enters plant life by photosynthesis, and because animals live off plants, carbon atoms from the atmosphere, whether of atomic weight 12 or 14, eventually circulate through the whole animal and vegetable world, returning to the atmosphere by the process of putrefaction (*see* Fig. 2). Thus all living organic matter should be very weakly radioactive. First confirmation of this was obtained from measurements made on methane given off by City of Baltimore sewage! Subsequently Libby and his collaborators were able to measure the radiocarbon activity of living wood. The answer obtained was around 12·5 counts per minute per gram of carbon, in remarkably good agreement with the theoretical estimate that Libby had made and corresponding to about one carbon-14 atom per million million carbon-12 atoms (more precisely 1 in 8×10^{11}).

The carbon-14 content of carbon that is in exchange with the atmosphere should remain at a constant level such that the loss of carbon-14 by radioactive decay is just balanced by the creation of new carbon-14 atoms by cosmic-ray neutrons. But in dead wood, for instance, the decaying carbon-14 atoms are not replaced and consequently the specific radioactivity should slowly decrease—by 1% every eighty years on the average. This decay rate corresponds to the carbon-14 half-life of 5800 years (the time taken for one half of an isolated sample of carbon-14 atoms to decay). Libby and his collaborators saw the immense potentialities in age determination and made an experimental test[2] of the method by taking samples of wood from the tombs of the Egyptian kings, Zoser and Sneferu. From historical records it was known that Zoser and Sneferu died around 2700 B.C. and 2625 B.C. respectively, and consequently, assuming that the wood for the tombs was cut at about the same time, its specific radioactivity should be a little over half the value for living wood. The expected value (averaged for the two tombs) was 7·15 (±0·15) counts per minute per gram of carbon; the value measured experimentally by Libby and his colleagues was 7·04 (±0·2) counts per minute per gram.

After further checks with samples of known age had been carried out, the way was open to reverse the process and predict ages from the specific radioactivity measurements. Since then the method has gone from strength to strength, until today there are some forty radiocarbon laboratories in operation all over the world. The dates obtained have not always agreed with the previous estimates made by archaeologists. Sometimes the technique has been at fault, either because the sample used was unsatisfactory or because of defects in the measuring apparatus but in other cases the radiocarbon method has given consistent but quite unexpected answers. An example is the beginning of the Neolithic Age in Europe—the New Stone Age in which settled farming replaced hunting as a means of livelihood. The accepted estimate among archaeologists a few years ago was around 2000 B.C. However, when relevant material was submitted to radiocarbon tests the answers stuck obstinately around the 3000 B.C. mark. At first archaeologists were inclined to shrug off these disturbing results, pointing to other circumstances in which radiocarbon dates had been wrong, but eventually the scientific evidence became so overwhelmingly conclusive that it had to be admitted

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that the evidence for 2000 B.C. was not unimpeachable. The earlier start to the Neolithic Age is now accepted.

Obviously, the periods for which radiocarbon dating is most valuable are those prior to the keeping of historical records; because it is difficult to reduce the likely error to below one or two hundred years, it is not often that the method can give any additional information once written records have been started—though correlation of the Mayan calendar with the Christian is just such a case. Besides archaeological research, radiocarbon dating has application in a wide field of other studies connected with the past. One of these is *paleobotany*—a study of how the *flora* on the earth's surface developed to its present state, particularly since the last Ice Age. Variations in climate are reflected in the types of trees and shrubs growing—of which evidence remains in the form of the minute pollen grains left behind—and so if the botanical changes can be dated, then the climatological changes are too. Radiocarbon dates[3] for the final phase of the last Ice Age are around 8300 B.C. This is in striking agreement with the date of 8100 B.C. arrived at by the *varve-counting* (counting the annual layers of sediment deposited by slowly melting glaciers). More detailed dating of the botanical changes has indicated that the amelioration of the climate in Britain following the retreat of the glaciers was probably sufficiently rapid for a noticeable increase in average temperature to have occurred during the span of a man's life.

Measurement of the radioactivity is far from easy. Not only are the number of counts per minute few but the beta rays emitted are of low energy (160 keV), so low that they can be appreciably attenuated by a sheet of aluminium less than one thousandth of an inch thick. One of the best methods for determining C^{14} content is to convert the carbon of the sample into carbon dioxide and use it as the counting gas in a proportional counter. This counter—about a litre in volume—must be carefully shielded from cosmic rays, and this necessitates several tons of steel. In Britain there are radiocarbon installations at the British Museum, at the Botany Department of Cambridge University and at the National Physical Laboratory, Teddington.

The radiocarbon concentration in the atmosphere today is about 30% higher than previously because of the creation of carbon-14 in hydrogen-bomb tests. This necessitates special precautions in the measuring technique but it does not invalidate application of the method—as long as the effect is eliminated from the modern reference value with which the radiocarbon activity of the ancient sample is compared. This reference value must anyway be deduced from a sample of known age (for example, a tree-ring) which ceased growth prior to 1850. This is because one of the consequences of the industrial revolution has been the release into the atmosphere of very "old" carbon (from coal) which, being deficient in carbon-14, has had a diluting effect.

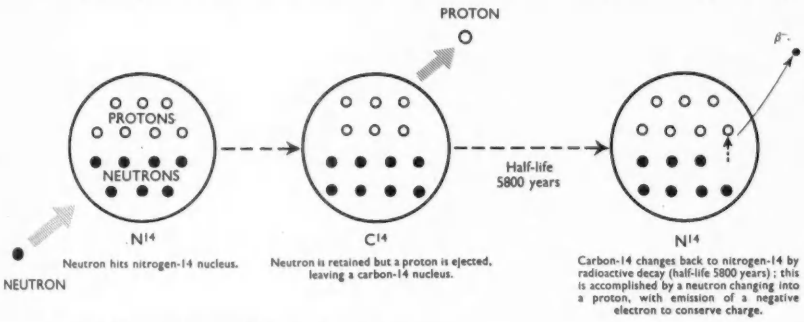
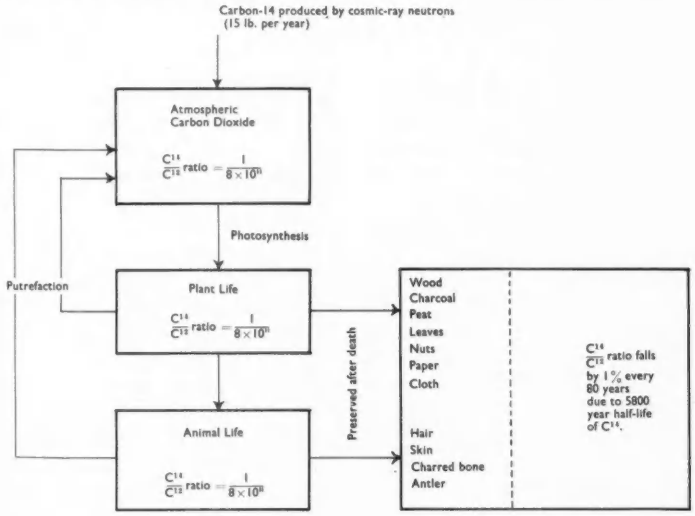

PROTON
PROTONS
NEUTRONS
Half-life
5800 years
N14
C14
N14
NEUTRON
Neutron hits nitrogen-14 nucleus.
Neutron is retained but a proton is ejected, leaving a carbon-14 nucleus.
Carbon-14 changes back to nitrogen-14 by radioactive decay (half-life 5800 years); this is accomplished by a neutron changing into a proton, with emission of a negative electron to conserve charge.

FIG. 1. Formation and decay of carbon-14.

FIG. 2 (*below*). Simplified carbon cycle. Atmospheric carbon dioxide is not only taken up by plants but also enters the oceans as dissolved carbonates so that seashells can be dated also.



NEUTRON ACTIVATION ANALYSIS

Neutrons occupy a special place in applied nuclear physics because of the ease with which they can penetrate the nucleus of an atom and cause a transmutation. This is because they are uncharged; protons and alpha particles are repelled by the positive charge carried by the nucleus, whereas electrons are not heavy enough to disturb the nucleus unless they are travelling very fast. Suppose we wish to know the percentages to which copper and gold are present in a silver coin—for reasons which will appear shortly. One way of doing this is to see what radioisotopes are produced when the coin is subjected to the intense neutron flux inside a nuclear reactor. The addition of a neutron to the naturally occurring stable isotope of gold (Au^{197}) produces gold-198. This is radioactive with a half-life

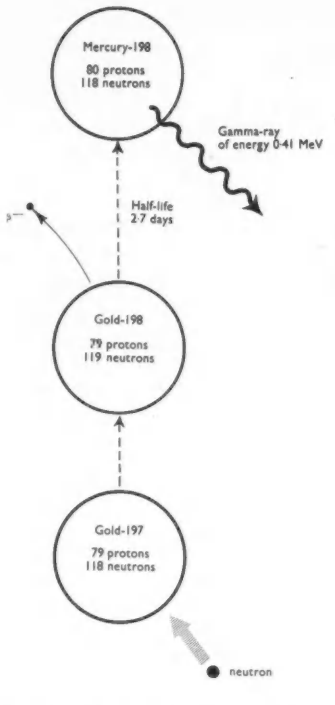


FIG. 3. Neutron activation analysis of gold. Emission of 0·41 MeV gamma rays after neutron bombardment indicates presence of gold-197.

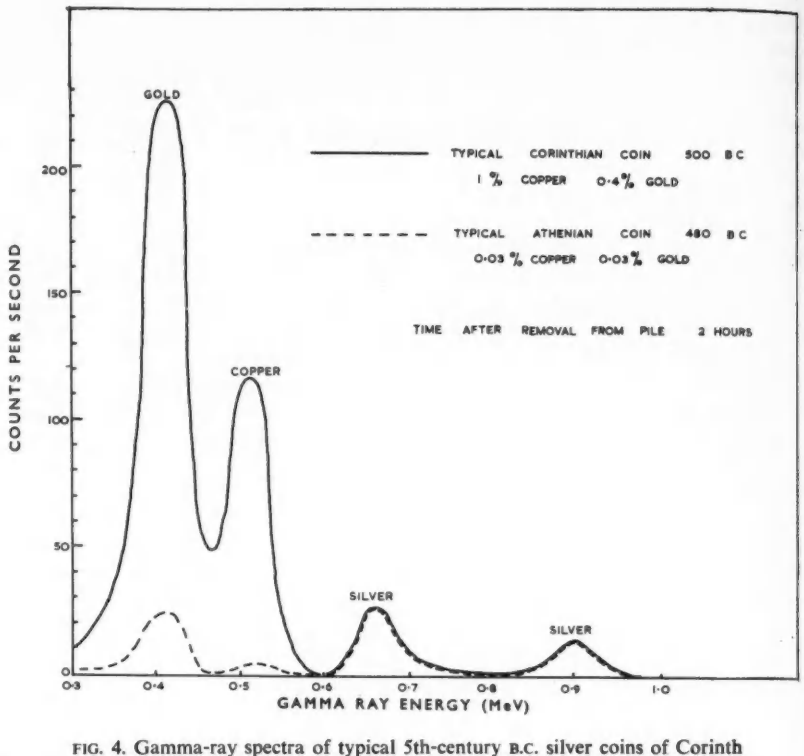
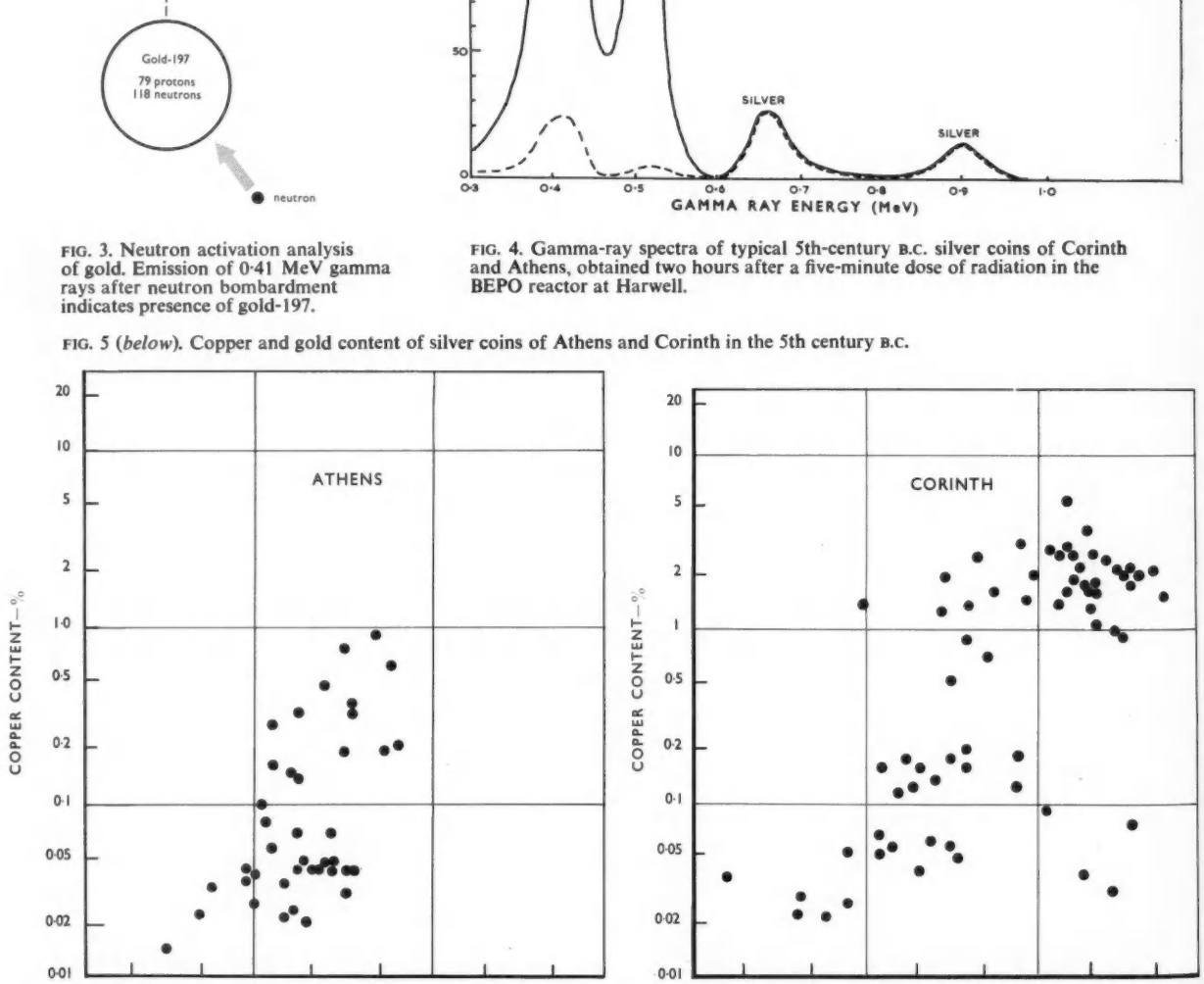


FIG. 4. Gamma-ray spectra of typical 5th-century B.C. silver coins of Corinth and Athens, obtained two hours after a five-minute dose of radiation in the BEPO reactor at Harwell.

FIG. 5 (*below*). Copper and gold content of silver coins of Athens and Corinth in the 5th century B.C.



of 2·69 days, emitting gamma rays of energy 0·41 MeV as well as beta particles (*see* Fig. 3). The use of a *gamma-ray spectrometer* allows easy identification by measuring the energies of the gamma rays emitted by the coin and using the half-life with which each energy of gamma ray decays as a confirmatory check of the identity of the isotope from which it is emitted. A typical gamma-ray spectrum is shown in Fig. 4, the peaks at 0·41 MeV, 0·51 MeV indicating the presence of gold and copper respectively and the height of the peaks being a measure of the percentages. The presence of silver is indicated by two peaks—at 0·66 MeV and 0·89 MeV—corresponding to two different energies of gamma ray. Although the coin is mainly silver, the corresponding peaks are no higher because silver is relatively insensitive to neutron bombardment.

The importance of neutron activation analysis in archaeology, particularly for coins, is that when used in conjunction with a gamma-ray spectrometer it can be completely non-destructive. The only effect on the coin is to make it weakly radioactive for a time, but usually far below any level that would harm even a museum curator who afterwards decides to carry it around with him in his waistcoat pocket.

A striking demonstration of this technique has been made by Miss Vera Emeleus of the Oxford University Archaeological Research Laboratory. Irradiating a dozen or so coins at a time in the BEPO reactor at Harwell, she has determined the percentage of gold and copper present as impurities in some six hundred ancient Greek silver coins (*see* Fig. 5). Since gold could not be separated from silver by any refining process known to the ancients, the gold content of the coin depends only on the ore from which the silver was extracted. Coins from Athens of the 5th century B.C. had a distinctively low gold content—0·06% or less; it is presumed the silver came from the rich, deep-lying veins of the neighbouring silver-mines at Lavrium. On the other hand, silver coins from near-by Corinth—a city without local silver-mines—have a very variable gold content, sometimes as high as 0·5%. The question of the source of Corinth's silver has often been posed by numismatists. Was it the nearest to hand at Lavrium or did the varying degrees of enmity between Athens and Corinth stifle such trading? The answer obtained from the neutron activation analyses rules out Lavrium as the *only* source of Corinth's silver but suggests that it was the source of some of it; in fact, the analyses give the sort of picture that would correspond to the alternating periods of war and peace between the two cities.

(Heberden Coin Room of the Ashmolean Museum, Oxford)

FIG. 6. Silver tetrobols of Macedon—alternative types of the same denomination. Neutron activation analysis revealed the copper content of the "riderless horse" type was as high as 24%, whereas the impurities in the "with rider" type were less than 0·3%.

In contrast to the difficulty of removing traces of gold from silver, the copper would be removed by the process of cupellation (heating in a blast of air) which was applied to the argentiferous lead extracted from the crude ore. This process oxidised away the lead and, incidentally, the copper. The low copper content (less than 1%) of Athenian silver is a tribute to the skill of their master-smelters. Higher copper percentages in the silver of other cities reflect a lower degree of competence, but in some cases systematic changes in the copper content can be interpreted as a deliberate addition, either with the intention of producing a more durable coinage or for debasement. The neutron activation analyses have revealed a curious practice that persisted in the mint throughout the 5th century B.C. at Macedon. Fig. 6 shows alternative but contemporary types of obverse face of a denomination known as the *tetrobol*. Whilst all coins of the "with rider" type had a copper content of less than 0·25%, the "without rider" types had copper contents varying between 5% and 24%. This was deliberate debasement on a grand scale indeed! Possibly the "without rider" tetrobols were a token issue for internal use only, the intrinsically more valuable "with rider" tetrobols being reserved to maintain Macedon's monetary reputation in export markets. More fancifully, one can hypothesise that the significance of the symbol was known only to the initiates of the mint, who grew rich on the surplus silver.

X-RAY FLUORESCENT ANALYSIS

The characteristic gamma rays which enable an element to be identified in the foregoing method are emitted by the nucleus after activation by neutrons. In analysis by X-*ray fluorescence*,[5] it is the orbiting electrons of the atom that are stimulated. As is implied by *fluorescence*, both the stimulating agent and the characteristic radiations are X-rays. A high voltage tube produces the primary X-rays and when these impinge on the material being analysed, electrons may be ejected from the inner shells of atoms in the surface. Other electrons fall back in place of the ejected electrons and X-rays are emitted (*see* Fig. 7). These secondary or fluorescent X-rays have a precise wavelength which is characteristic of the element concerned. In a careful study of these secondary X-rays, Moseley showed in 1913 that the higher the atomic number of the element, the shorter was the wavelength. The wavelengths present in the secondary radiation are determined

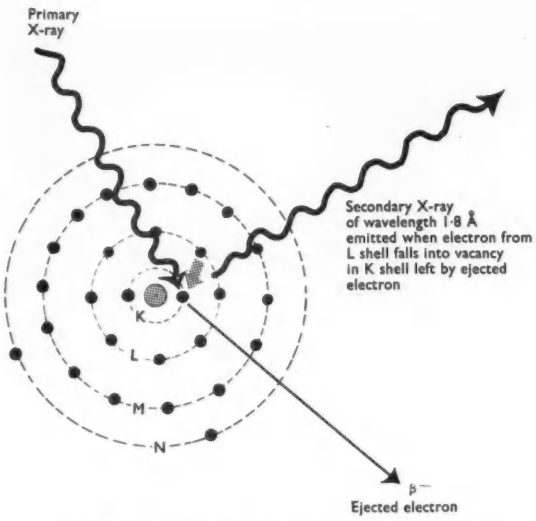
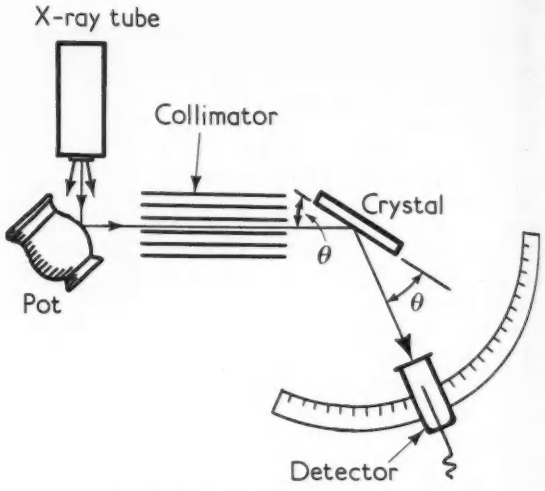


FIG. 7. Diagram illustrating x-ray fluorescence in cobalt. Detection of 1·8 Å x-rays that are characteristic of cobalt reveals presence of this element in sample under investigation.



From "Physics and Archaeology", by M. J. Aitken (Interscience)

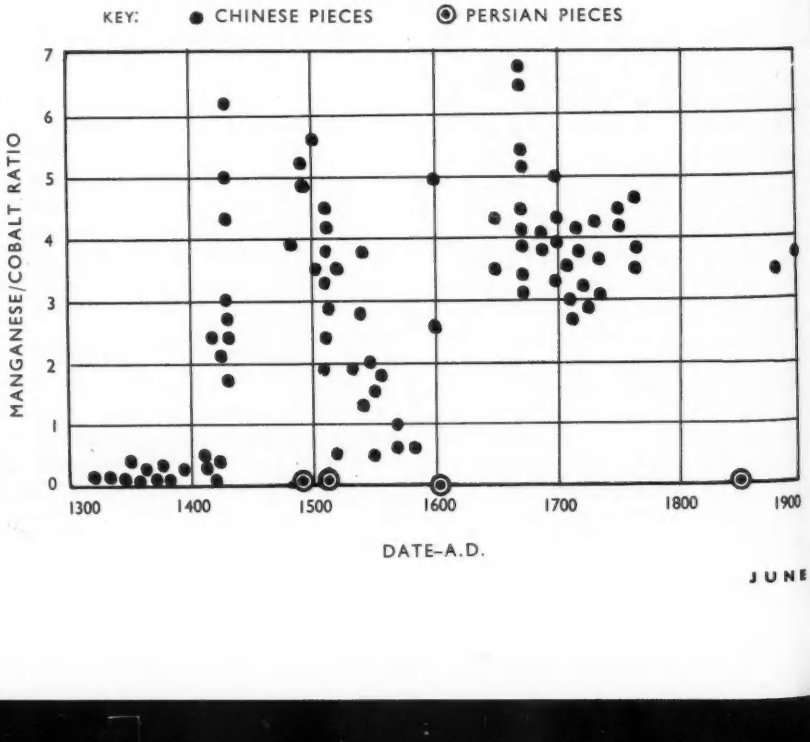
FIG. 8. Schematic drawing of equipment for x-ray fluorescent analysis. X-rays from tube cause fluorescence of atoms in the surface of the pot. The wavelengths present in the fluorescent radiation are determined by means of the diffraction crystal which reflects a given wavelength only at one particular angle of incidence.

by means of a diffraction crystal (*see* Fig. 8). Reflection of a given wavelength occurs only at a given angle to the surface of the crystal (which can be of lithium fluoride, sodium chloride, or quartz, for example). The angles at which reflection occurs are determined by detection with a photographic plate, or more expeditiously with a Geiger counter or a scintillator and photomultiplier. Reference to a chart then shows to which elements the observed wavelengths correspond and the intensity of each wavelength gives a measure of concentration of the corresponding element.

In contrast to neutrons and gamma rays, x-rays are easily absorbed in matter; whereas the neutron technique gives an analysis of the whole volume of a coin, x-ray analysis deals only with a thin surface layer of the order of one thousandth of an inch thick. Thus x-ray analysis of coins can give misleading results because of corrosion and surface enrichment and will not detect fakes made by plating silver on to some cheaper metal. Although this is a drawback for coin analysis, it is a positive necessity for analysis of the constituents used in the glaze on pottery. Such analyses can often be used as a test of whether a piece of pottery is genuine and also as a method of gaining information about the techniques used by ancient craftsmen.

A striking demonstration of the way in which carefully planned analyses can reveal general historical and economic information has been carried out by Dr Stuart Young.[6] Using the automated x-ray fluorescent spectrometer built by Dr E. T. Hall at the Oxford Archaeological Research Laboratory, he determined the ratio of manganese to cobalt in the blue pigment used in the decoration of some eighty pieces of the fine and valuable Chinese and Persian porcelain known as "blue-and-white". This was made in China from the beginning of the 14th century, continuing through the Ming and Ching dynasties. Variations between contemporary pieces in the quality of the colour had been ascribed to the use of imported cobalt ores for the more refined pieces

FIG. 9. Results obtained by x-ray fluorescent analysis of the blue pigment in Chinese blue-and-white porcelain show that the importation of low-manganese cobalt ores from outside (presumably Persia) ceased by the end of the 16th century and also that the high-manganese native ore was not used until the beginning of the 15th century.



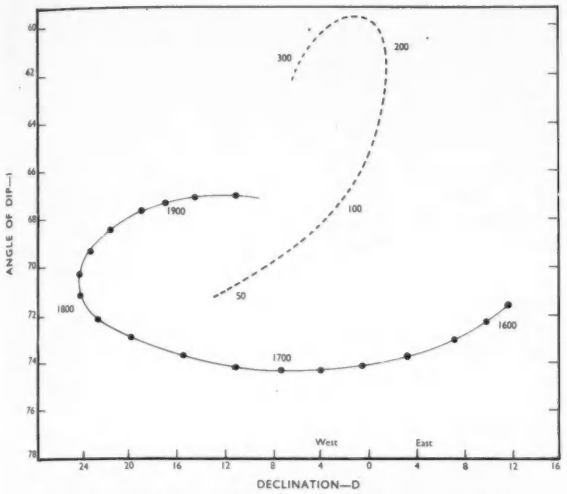


FIG. 10. Secular variation of the Earth's magnetic field (central Britain). The solid curve was obtained by direct measurement. The dotted curve shows tentative values inferred from measurements of the remanent magnetism in the baked clay of Roman pottery kilns. All dates are A.D.

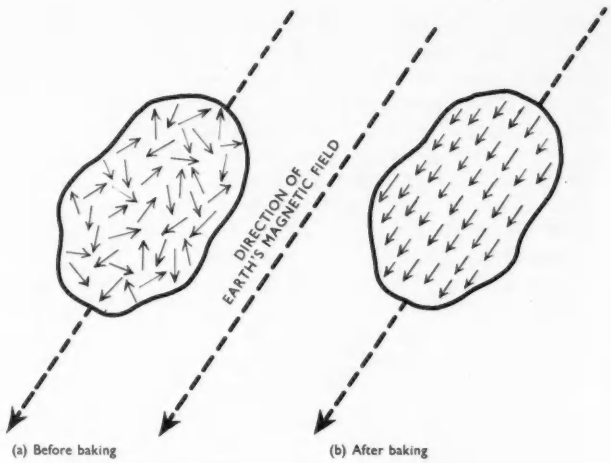


FIG. 11. Diagram illustrating acquisition of thermoremanent magnetism by a lump of clay. The arrows represent the magnetic domains of the small percentage of iron oxide present.

and the use of native cobalt ores for the less refined ones. It was possible to test this hypothesis by measuring the ratio of manganese to cobalt, for the cobalt ores occurring in China contain, without exception, a high proportion of manganese, while those of Persia (the presumed source of importation) and the Middle East are manganese-free.

No correlation with quality was in fact found but the investigators discovered that the use of imported ore ceased by the end of the 16th century and that native ore was not used until the beginning of the 15th (*see* Fig. 9).

MAGNETIC DATING

Like radiocarbon dating, *magnetic dating*[4] is another method which is based on a natural phenomenon external to man. The time-variant quantity that is the basis of this technique is the direction of the earth's magnetic field. This direction is defined by the magnetic declination (the angle between true north and magnetic north) and the angle of dip (the inclination to the horizontal of the magnetic lines of force). The *secular variation* of these angles over the past few hundred years is known from scientists' records of direct observations made on magnetised needles (*see* Fig. 10), but a fortuitous record is available almost since man discovered fire. When clay is baked, the magnetic domains of the small percentage of iron oxide present (in the ferrimagnetic forms of magnetite and haematite) are preferentially aligned by the earth's magnetic field (*see* Fig. 11). When the clay cools this domain alignment remains "frozen" and the clay has a weak magnetic moment (specific magnetisation of from 0·0001 to 0·1 e.m.u. per gram) the *direction* of which is identical with that of the earth's field. This phenomenon, termed *thermoremanent magnetism*, has been comprehensively investigated by Prof. E. Thellier of l'Institut de Physique du Globe, in Paris. The same phenomenon is responsible for the magnetism acquired by rocks millions of years ago as they cooled from the molten state; measurements of the magnetic direction retained in volcanic lava allows the positions and orientations of the continents during the early stages of stabilisation of the earth's crust to be reconstructed.[7]

In order to find the ancient magnetic direction recorded by archaeological firing, it is, of course, essential that the baked clay be found exactly in the position in which it cooled down. This condition is satisfied in pottery kilns, hearths, ovens, and furnaces where clay was used in the construction or as a lining because of its unique refractory properties. To determine the magnetic direction, a lump of the clay must be taken to the laboratory for measurements by a specially sensitive magnetometer, but before the lump is detached its orientation must be precisely determined. It is partially enclosed in plaster (*see* Figs. 12 and 13), the top surface of which is made horizontal. A line is sighted on this surface from a theodolite and a sun-shoot is made, thereby making it possible to determine the orientation of the line on the plaster with respect to true (or geographic) north. The laboratory measurements determine the magnetic direction with respect to the line on the plaster and so the angles of declination and dip can be found. With a dozen samples a good average can be obtained for each structure.

The curve of Fig. 10 suggests that the secular variation is regular and predictable with a periodicity of between four and five hundred years. This, however, hardly fits in with the current belief that the secular variation is due to near-surface disturbances in the electrical currents in the earth's core from which the earth's field originates. Early measurements by Thellier on baked clay samples that were datable from archaeological evidence dispelled any hope that the secular variation is in fact well behaved despite the theoretical argument. To use the magnetic dating technique, then, it is first of all necessary to establish the secular variation curve from well-dated burnt clay

samples of the period concerned. Since the secular variation is different at different parts of the earth's surface, this reference curve must be established for each region of five hundred miles across or so in which the method is to be applied. The necessity of establishing a reference curve is a serious drawback that does not afflict the radiocarbon dating method which, to a close approximation, is absolute. Magnetic dating offers the advantage, however, of much higher precision.

The information that can be obtained from thermoremanent magnetism is not limited to dating. For example, the technique helped solve the question of whether the broken-off head of a Greek terra-cotta figurine did in fact belong to the body. The magnetic directions were measured for the head and for the body. These indicated that had the two been fired together it could only have been with the head twisted backwards in an anatomically impossible position. In addition, the specific magnetisations in each part differed by a factor of three—indicating either different clay or different firing conditions.

THE PROTON MAGNETOMETER

Although there are many interesting secondary applications of thermoremanent magnetism, the most important is still the magnetic dating of pottery kilns. These kilns occupy a special place in archaeological research because pottery *fragments* (or *sherds*), being durable and common, often form the main evidence about the history of an archaeological site. The occurrence of similar types of pottery on two different sites forms a link between them, and dating evidence obtained on one can be carried over to the other; sherds are rather similar to sub-standards in physics. A pottery *kiln* is the source of these sub-standards, and if several different types of sherd are found in the same kiln their contemporaneity is established, since the useful life of a kiln was only a few years. In addition, there is the possibility of finding a layer of complete pots left unloaded in an abandoned kiln.

Pottery kilns are preserved for us today because they were dug into the ground (*see* Fig. 14) to simplify construction and give good thermal

FIGS. 12 and 13. Taking samples for magnetic dating. (*Right*) Before being detached for removal to the laboratory, the lumps of clay are partially enclosed in plaster. A line on the top surface records the exact position of firing. (*Left*) Shooting a line on to the surface by means of a theodolite.

(*Thomas Thompson*)

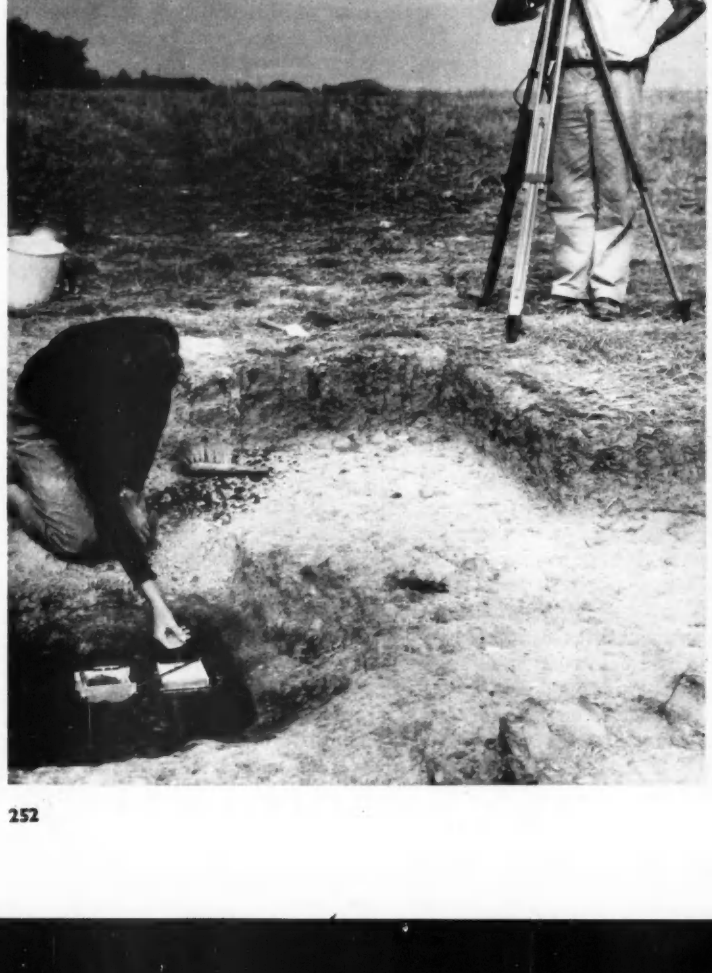
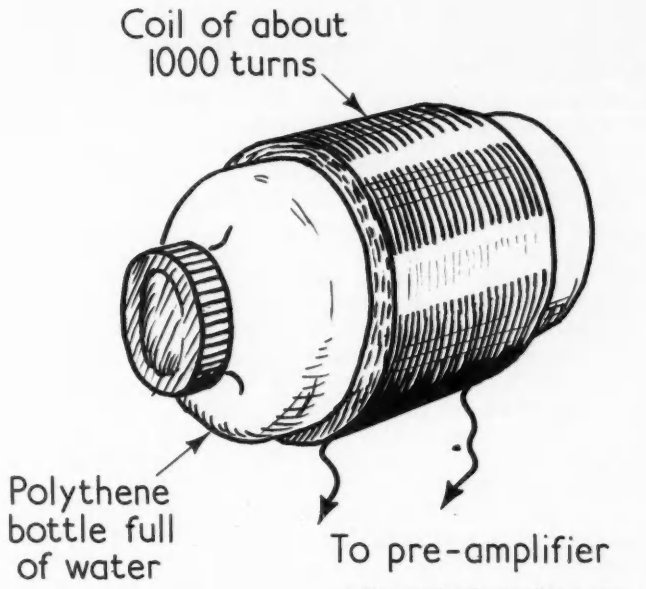


FIG. 14 (*below*). Roman-British pottery kiln.

insulation. Although this circumstance has preserved them, it has made them difficult to find, however, for the old ground surface is often several feet below the present one due to the gradual accretion of soil. A critical situation arose in 1958 when re-routing of the Great North Road near Water Newton in Huntingdonshire took its path across the outskirts of the Roman town of Durobrivae. From other evidence, it was expected that the two-mile stretch of new road might cut into pottery kilns producing the important colour-coated (or Castor) pottery; it was vital that these be excavated with the careful trowel of an archaeologist rather than the all-embracing grab of a mechanical digger! However, the chances of locating the kilns in advance by random trial-trenching seemed infinitesimal. The situation was saved by a method put forward by Dr J. C. Belshé, a geophysicist of Cambrdge University. He pointed out that the thermoremanent magnetism in the baked clay of a kiln should be strong enough to increase slightly the magnetic field intensity at ground-level. The conventional method of measurement—observing the torque on a magnetised needle—although sufficiently sensitive, would have been too slow in operation to survey the area in time because of the necessity of levelling the instrument for each reading. On the other hand, the new proton free-precession technique of measuring the earth's magnetic field[8]—already in use in geology and geophysics—was ideally suited for the purpose. Following Belshé's suggestion, a fully transistorised proton magnetometer[4] was built by the Archaeological Research Laboratory of Oxford University. Besides being portable, weighing only 22 lb. including accumulators, this instrument is rapid in operation, enabling readings at a rate of ten a minute. By this means, the long strip scheduled for road construction in 1958 was surveyed in the space of a few weeks. Although only one kiln was found, the negative result meant that the archaeologists could rest easy. The method was more fully demonstrated the following year when six important kilns were pinpointed in a section to which access was obtained only a month before road construction began.

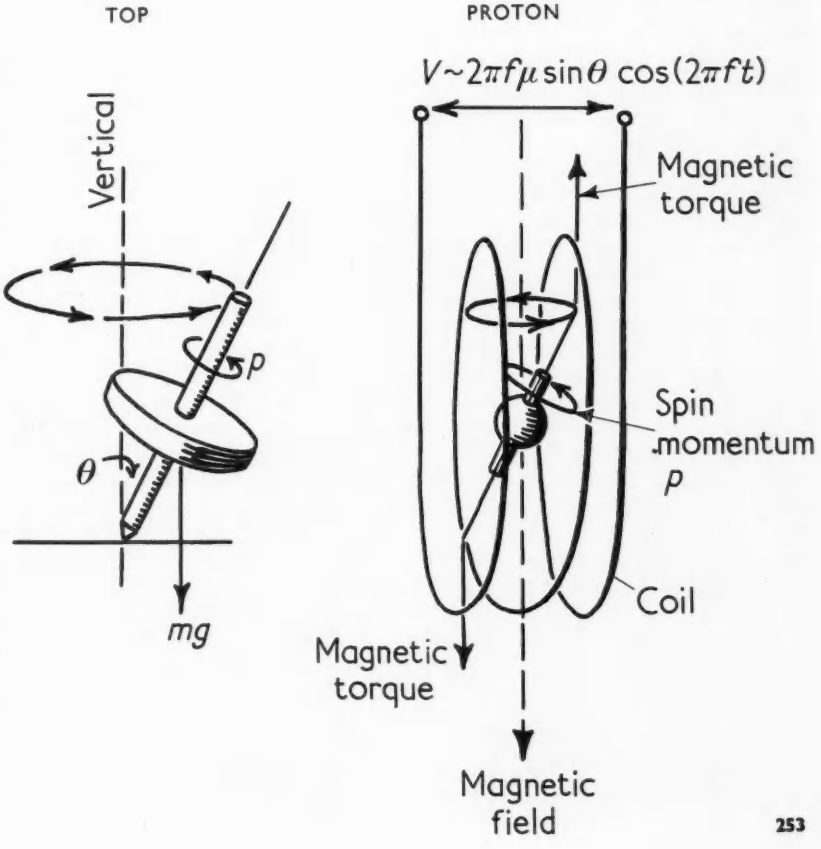


"Physics and Archaeology" (Interscience)

FIG. 15 (*above*). Detector bottle for proton magnetometer.

FIG. 16 (*below*). Precession of top (*left*) illustrates precession of proton in a magnetic field (*right*). The frequency of precession of the proton is proportional to the magnetic field and induces a minute alternating voltage in the coil around the bottle.

"Physics and Archaeology" (Interscience)



The proton magnetometer has been used on about thirty sites in Britain and the technique is now being taken up by archaeologists in America. It has proved itself a very powerful tool, not only in locating pottery kilns but also in finding filled-in ditches, and the pits which abound in the interior of an Iron Age hill-fort. Pits and ditches show up magnetically because an incidental effect of cultivation on soil is to increase the magnetic susceptibility. Weakly ferrimagnetic *haematite* (α–Fe_2O_3), present to a small percentage in the soil, is converted to the more highly ferrimagnetic *maghemite* (γ–Fe_2O_3). The process is favoured by the action of fire and a high humus concentration; some filled-in pits, perhaps used as latrines, have produced as big a change in the magnetic field intensity as that from a pottery kiln. This is about one part in a thousand (0·1%), or 0·0005 oersted. On the other hand, where the filling is comparatively sterile the change may be only just distinguishable from the random changes due to natural variations in the condition of the top-soil; the magnitude of these is in the order of one part in 25,000, or 0·00002 oersted.

The sensitivity necessary to detect such small changes in magnetic field intensity is easily obtainable with the proton magnetometer. Although it depends on the same fundamental properties of nuclear magnetic moment and nuclear spin, the free precession technique differs from the more commonly known nuclear magnetic resonance used with strong magnetic fields for the investigation of molecular structure. The protons under observation are the hydrogen nuclei in a 200-c.c. bottle of distilled water. A thousand-turn coil of wire is wound on the bottle (*see* Fig. 15) and the essential preliminary to a measurement—a polarising field of a few hundred oersteds along the axis—is produced by passing a current of 1 amp. through the coil. This produces preferential alignment of the protons along the axis. The coil is held with the axis horizontal in the east–west direction; when the polarising current is cut off, the protons experience a magnetic torque tending to align them along the lines of force of the earth's field. But because of their spin angular momentum, the protons behave like gyroscopes and precess about that direction instead (*see* Fig. 16). The frequency of this precession is exactly proportional to the magnetic intensity. Although the proton magnetic moment is only $1{\cdot}4 \times 10^{-23}$ e.m.u., the precession can be detected because the preliminary polarising field has ensured that the protons precess in phase; a minute but detectable voltage—about a microvolt—is induced in the coil which is then switched to a highly selective amplifier with a gain of about 100,000. The frequency is in the region of 2000 c/s for the magnetic intensity found over most of Britain—about 0·48 oersted. The measurement of this frequency to an accuracy of one part in 50,000 calls for subtle transistor techniques but, fortunately for the archaeologist, the operation of the instrument is very simple. The measurement is initiated by pressing a button. After five seconds each meter dial indicates a digit, and the four-figure number formed by these digits is a measure of the magnetic intensity.

TWO NEW METHODS

In conclusion I shall mention two very new techniques that are still in the early stages of development. The first of these—*thermoluminescent dating*—once again concerns baked clay. The alpha particles from the uranium and thorium present as impurities (a few parts per million) create lattice defects in the crystal structure of minerals in the clay. This *radiation damage* can be detected because the defects act as electron traps; when the clay is heated (to say 400°C) the electrons are released and give up their energy as visible light. This is measured with a specially selected low-noise photomultiplier. The amount of light given out in this way is proportional to the length of time the damage has been accumulating, starting from the last baking of the sample since heating wipes the slate clean of all previous damage. The preliminary work[9] carried out by Prof. G. Kennedy of California University is highly encouraging.

The other new method is much simpler and is akin to one of the earliest dating methods of all—tree-ring counting. Glass objects buried in the soil or submerged under water often undergo a slow chemical deterioration, producing a weathering crust at the surface. It is this crust that is responsible for the strikingly colourful irridescence of glass.

When examined in cross-section under a microscope these crusts are found to consist of individual layers about one ten-thousandth of an inch thick. By counting the number of layers in crusts of glass objects of known history, R. H. Brill and H. P. Hood of the Corning Museum of Glass, New York, have shown[10] that each layer is the result of one year's decomposition, the layers being distinct because of seasonal variations of decomposition rate. With the use of this technique, a wine-bottle salvaged from a sunken British ship appeared to have been submerged some time between 1765 and 1785, with a most probable date of 1779. This agreed well with the known historical fact that the ship was sunk during the seige of Yorktown in 1781. The method promises much and it is nice to think that the microscope can still rival the expensive paraphernalia of modern nuclear physics.

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SHAPING METALS ELECTROCHEMICALLY

DAVID FISHLOCK

The selective dissolving away of a metal surface is proving to be superior to conventional machining methods in certain instances, particularly where the metals are very hard or the desired shapes complex.

The forming and shaping of metals by dissolving away material electrochemically may, at first glance, seem far-fetched and impractical, but it is hardly more so than the use of explosives, electron beams, and sparks. All of these unusual metal-cutting "tools" are now being employed in industry and electrochemical machining promises to establish itself in a large way.

Any metal—element or alloy—can be accurately reduced to almost any shape and size by making it the positive electrode in an electrolytic cell and using a properly shaped negative electrode (Fig. 1). The idea itself is not new but a way of doing it fast enough for production on a practical scale is a relatively recent achievement.

All metals dissolve at a rate which depends not on their physical properties but on the amount of current flowing between the anode and cathode and on the metal's electrochemical equivalent. The major problem is getting a sufficiently large current to flow.

Most metallic engineering components are shaped partly or wholly by machining—that is, by cutting away unwanted metal as swarf on a machine tool such as a lathe, drill, or grinding machine. This approach is inherently wasteful of metal but in general produces a much more accurate component than the so-called "swarfless" techniques—forging, drawing, extruding, etc. Moreover, it is a reasonably fast way of shaping the more commonplace metals.

But industry is finding an increasing need for uncommon metals—"exotic" metals like molybdenum and tungsten, Nimonic (high-nickel) and cobalt alloys, and very tough tool steels. These metals approach and may exceed in hardness and strength the materials used as cutting tools on the machine. Adaptations of conventional machining techniques have been devised to cut these "superalloys" but they are generally slow and costly. Hitherto, cost has been disregarded, the end justifying the means. But the alloys are now finding a wider market, far beyond the missile and gas-turbine industries that originally demanded them.

It is significant that at the recent press showing of a film on machining Nimonic alloys most of the discussion afterwards related to a technique which had not been filmed—electrochemical machining.

In concept, conventional metal cutting is a crude way of shaping metal. True, an automatic lathe which sucks in a coil of wire and spews out 1000 or more finished components an hour that are accurate to 0·0002 in. and better seems anything but crude. But the underlying principle of using one metal to rip another apart lacks finesse.

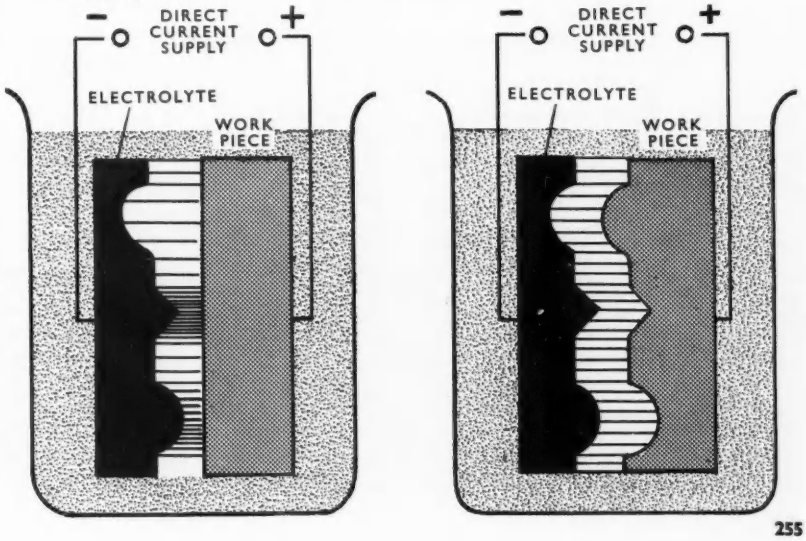
In contrast, electrochemical dissolution is a highly sophisticated technique. Under the influence of an electric current, metal atoms leave the surface "one-by-one" and become dispersed in the electrolyte as ions. There is no solid swarf, no vibration, no fast-spinning tool or workpiece, no metallurgical damage to the metal (through overheating, for instance) and the metal emerges from the operation with a polished surface in place of the customary machining marks.

But what makes electrochemical machining particularly attractive to production engineers is the fact that it offers a faster way of cutting very tough metals and a quick way of sculpting awkward contours in any metal, tough or otherwise.

MECHANISM OF DISSOLUTION

Let us now take a closer look at the mechanism of electrolytic dissolution. With the passage of current between anode (workpiece) and cathode in the electrolytic "cell", the electrolyte near the anode becomes highly charged with dissolved metal. As a result, the rate of dissolution slows progressively unless the charged electrolyte is removed. Agitation helps but with normal

FIG. 1. Diagram illustrating the principle of electrochemical shaping. By placing the cathode and workpiece a few thousandths of an inch apart (*left*), the electric current is concentrated at points at which the surface of the workpiece is to be dissolved away, leaving a facsimile of the cathode shape (*right*).



The author has spent seven years in industry as an electrochemist and is now Associate Editor of Metalworking Production, *a weekly engineering journal.*

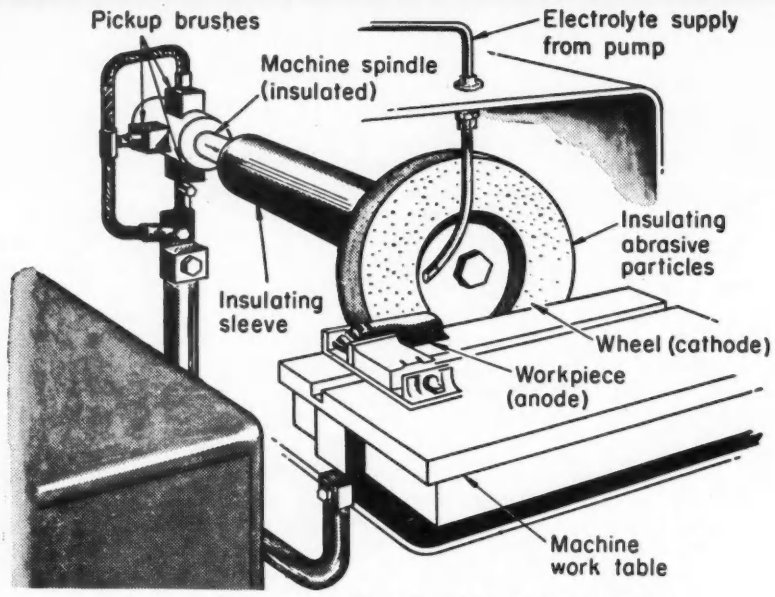


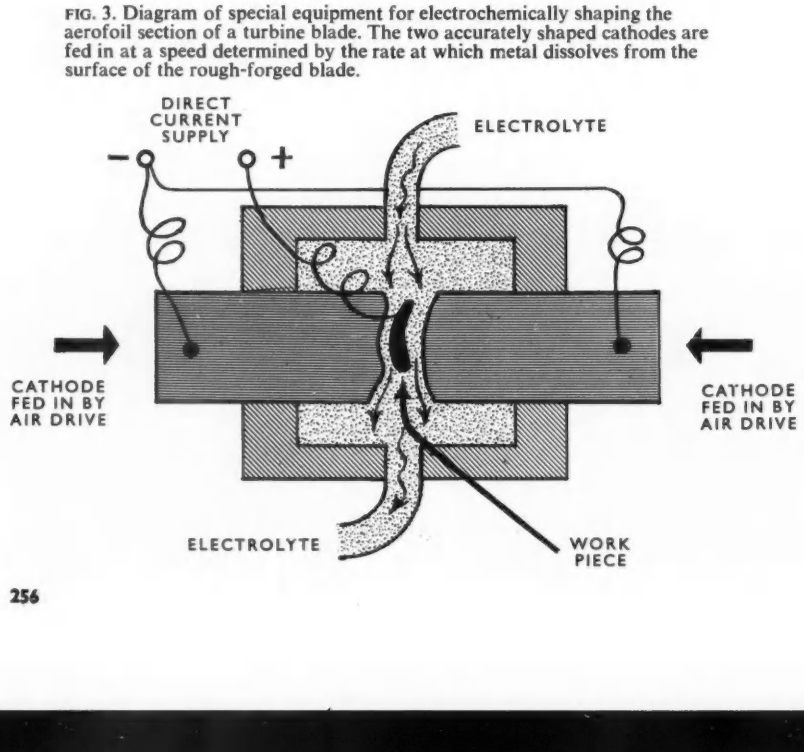
FIG. 2. Diagram of a grinding machine adapted for electrolytic grinding.

methods of stirring, a working limit is reached at a current density of 2 or 3 amperes/sq. in. A film of electrolyte 0·002 to 0·005 inches thick adheres to the surface of the anode and offers considerable resistance to attempts at dislodging it. More drastic methods of agitation are needed to shift the film and maintain a constant flow of fresh electrolyte over the surface of the anode.

There are several ways of achieving it and embodied in the most successful is the secret of how to increase the rate of metal dissolution from 0·003–0·004 in./min. at 2–3 amperes/sq. in. to 0·05–0·10 in./min. at up to 1500 amperes/sq. in. The cutting rate of even 0·10 in./min. hardly compares with a machine that can "hog" eighty pounds of metal off a big steel forging in three minutes (cf. claim made for an American turret lathe recently). But it does mean that a stainless steel or Nimonic turbine blade can be finish-machined from a rough forging in five minutes instead of the several hours normally needed.

The problem of bringing fresh electrolyte in contact with the surface being dissolved can be met in two ways: by moving the material through the liquid or by moving the liquid past the work. The molybdenum and tungsten wire and foil used in thermionic valves—both hard metals and extremely difficult to draw down to very small dimensions—have been electrolytically machined to size for some years by the first method. One company draws tungsten wire down to a diameter of 12 microns and then pulls it through an electrolytic cell to dissolve away another 2 microns. The same approach has been scaled up for heavy-gauge wire and strip. A recent patent (BP. 835,594) covers a method of electrochemically machining away the surface layers of steel wire up to 0·3 in. in diameter using a hot acid mixture as electrolyte; at speeds of 7·5 ft./min., current densities of 8–13 amperes/sq. in. can be used.

FIG. 3. Diagram of special equipment for electrochemically shaping the aerofoil section of a turbine blade. The two accurately shaped cathodes are fed in at a speed determined by the rate at which metal dissolves from the surface of the rough-forged blade.



ELECTROLYTIC GRINDING

The most widely used electrochemical machining technique today is electrolytic grinding, so named because of a superficial resemblance to conventional grinding practice (*see* Fig. 2). Instead of the usual grinding wheel of bonded abrasive grains, a wheel that conducts electricity is used. Abrasive or plastic particles bonded to the wheel serve mainly to keep the wheel (cathode) and workpiece (anode) apart. The electrolyte is usually flooded on to the fast-spinning wheel although in one application the wheel is made porous and the electrolyte is pumped through it. Either method ensures a vigorous flow of electrolyte over the surfaces; the scrubbing action of the particles bonded to the wheel ensures the removal of the surface film of electrolyte.

The distance between the wheel and workpiece is an important factor. For a heavy current flow and fast machining rates, this spacing must be kept to an absolute minimum—a few thousandths of an inch; the bonded particles are effective in keeping it at a constant, small value.

There is a tendency among those in industry to conceal the precise compositions of the electrolytes they use, but composition is of no great consequence. Broadly speaking, any fluid that conducts electricity well can be used—brine, sodium silicate, dilute acids, etc. There are secondary considerations in the choice of an electrolyte, however. Variations on and additions to a given solution can give better results with a given alloy—higher efficiency, minimal

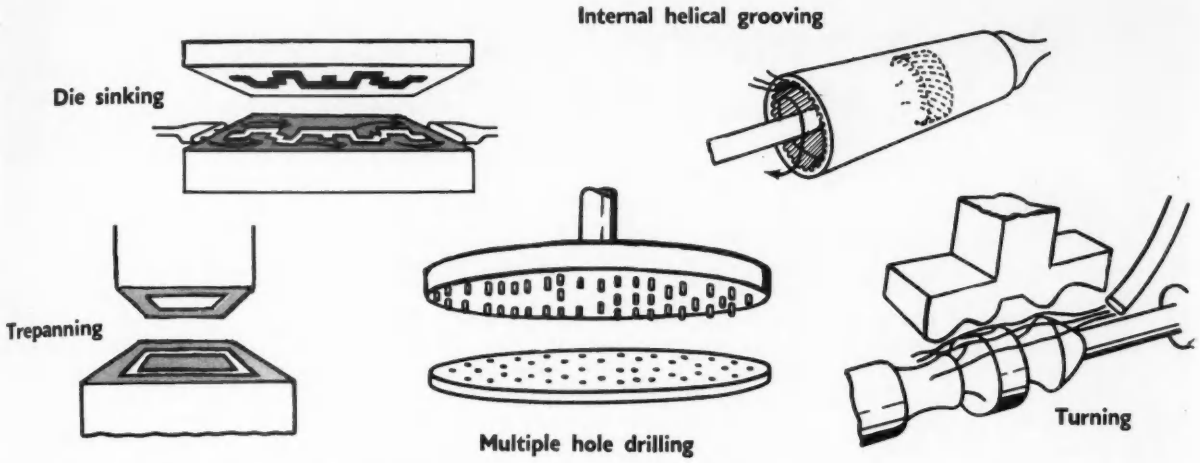


FIG. 4. Some of the metal-cutting processes which can be duplicated electrochemically.

etching, etc.—but it must not be highly corrosive or machine and operator will both suffer. It is also desirable that the electrolyte be able to retain a fair amount of metal in solution without its performance becoming impaired. An economic factor may well become significant before long—namely, whether the more costly metals can be reclaimed from the spent solution.

Electrolytic grinding is now established in industry. One supplier claims its equipment has been used to convert several hundred conventional grinders to the process. The main application so far is for the "grinding" of steel and carbide cutting tools. The advantages: a tool with a good surface finish which is unstressed and free from burrs—at a lower cost.

ELECTROLYTIC SCULPTING

Electrolytic grinding is virtually restricted to flat and concave surfaces, but a variety of special techniques have been developed recently which duplicate almost every metal-cutting process. They all embody the same two principles: a fast-flowing electrolyte and a very small inter-electrode spacing (0·01 in. or less).

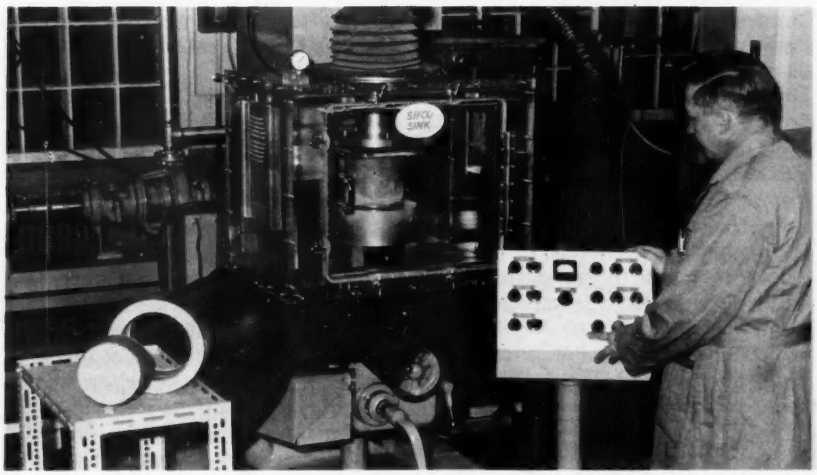
The fast flow is achieved by pumping—by literally squirting a jet of electrolyte past the electrodes at speeds that have gone as high as sixty to one hundred m.p.h. Maintaining the gap is the major problem, but one technique is to use a servo mechanism to keep the spacing constant. A simpler method is to determine the rate at which metal will be dissolved at a given current density and then pre-set the rate at which the cathode and workpiece are moved together (*see* Fig. 3).

Electrochemical machines that drill, cut, contour, and sink cavities are now beginning to find their way into production lines. They have been used to slice tungsten bars, drill 0·012 in. diameter cooling passages through the length of turbine blades, shape a *hardened* steel forging die in fifty minutes (a job that normally took seven hours and then only on unhardened steel), cut an awkwardly shaped pocket in stainless steel in eleven instead of forty-six minutes, sink a deep hexagonal hole in a "superalloy", and trepan a 7 in. diameter core from a block of tungsten (Figs. 4 and 5).

These examples and many more have so effectively proven the potential of electrochemical techniques for the forming of difficult metals, the protagonists are now turning their attention to the more easily cut metals—steels, brasses and aluminium. They claim that the machining of these metals electrochemically will make it possible to shift to simpler, lighter, vibration-free machines and produce, at the same time, finishes that are accurate, smooth, burr-free, and unstressed. It will also be possible, they add, to make complex cuts at higher speeds. Their arguments are beginning to attract attention.

FIG. 5. A job that would not even be attempted with conventional machining. The 10 in. diameter missile case (*left*) had a 7 in. diameter core removed by electrolytic trepanning in less than five hours.

(*Metachem Processes Ltd*)



MOTOR VEHICLES, AIR POLLUTION, AND AFTERBURNERS

W. L. FAITH

California's approach to its smog problem—a law requiring afterburners on motor vehicles—has attracted worldwide attention, but others would do well to study their own particular conditions before blindly taking the same course of action.

The determined efforts of Californians to solve their air-pollution (smog) problem by mandatory control of motor-vehicle exhaust has attracted world-wide attention—too much attention, perhaps, if one were to judge by the number of statements by people who want to adopt California's regulations as soon as control devices are developed and certified here. Statements of this nature are generally irresponsible because they neglect to recognise the importance of local conditions in air-pollution problems.

To understand the nature of the California smog problem, one must look at the meteorological and topographical features of the Los Angeles basin, where the problem first developed (Fig. 1). The 1600-sq.-mile basin is part of the Southern California coastal plain. It is surrounded on three sides by high mountains and on the west by the Pacific Ocean, from whence flows the prevailing westerly winds. Like all tropical and subtropical areas on the west coasts of continents, the late summer and early autumn bring conditions that are conducive to the development of smog: exceedingly calm mornings and early afternoons, intense sunlight, and a strong atmospheric temperature inversion produced by a pronounced subsidence of air as it flows clockwise round the semi-permanent high-pressure area to the west. Vertical and horizontal atmospheric movements are restricted in this stagnant air régime and pollutants accumulate until the afternoon sea breezes blow them across the mountains or the inversion is broken by radiation from the heated land. If Los Angeles were subjected to the myriad smokes and fumes from London's domestic and factory chimneys, the area would be well-nigh uninhabitable. Fortunately, little or no coal is burned in Los Angeles and the dusty industries are few and closely controlled.

Yet Los Angeles has an intense smog problem that is triggered by its famous sunshine. This is how it develops:

The six million persons in the Los Angeles basin own and operate three million motor vehicles, which daily send 7000 million cubic feet of exhaust gases into a restricted air mass. These gases contain 1000 tons of hydrocarbons, 4500 tons of carbon monoxide, and 500 tons of nitric oxide (plus a small amount of nitrogen dioxide). When the atmosphere is sufficiently restricted, the concentrations of these gases become noticeable. The nitrogen dioxide molecule absorbs energy from specific wavelengths of sunlight[9] to form an activated molecule which, in turn, reacts with specific hydrocarbons, principally olefins, to form the celebrated Los Angeles smog that is characterised by a high ozone content (0·2–0·5 p.p.m.), a bevy of eye irritants, one or more vegetation-damaging materials, and a visibility-reducing aerosol (even at very low humidities, *see* Figs. 2 and 3).

Records show that the hydrocarbon content of the air has gone as high as 5 parts per million, the carbon monoxide content has reached 90 p.p.m., and nitrogen oxides have gone up to 3 p.p.m. Much lower concentrations are sufficient for smog formation.

An interesting point is that Los Angeles smog requires four simultaneous factors for its development: a restricted atmosphere, oxides of nitrogen in the proper concentration, hydrocarbons, and *sunshine*. Thus, it has become known as "photochemical" smog. Only when one understands the unique nature of Los Angeles smog does the recent California motor-vehicle pollution control law make sense.

BASIS OF MOTOR VEHICLE POLLUTION CONTROL

When the California Department of Public Health was directed by the Legislature in 1959 to establish ambient air standards for pollutants and limits for the emission of contaminants in motor-vehicle exhaust, the basic consideration was the knowledge available concerning photochemical smog and the probable need for controlling the automobile exhaust which provided the basic chemical reactants.

After a thorough study and a great deal of consultation with scientists and engineers, a set of standards were adopted by the State Board of Health.[6,7] The ambient air standards they established that are pertinent to the present discussion were an "oxidant index" of 0·15 p.p.m. for 1 hour (the selected measure of photochemical smog) and a carbon monoxide limit of 30 p.p.m. for 8 hours with a maximum of 120 p.p.m. for any one hour. Inasmuch as both contaminants had at various times exceeded these limits in Los Angeles, it was deemed appropriate to set limits for motor vehicles themselves.

Fortunately, there were sufficient data available to calculate the emissions from an "average" automobile. One problem the Department of Public Health faced was the determination of which of two reactants (hydrocarbons or oxides of nitrogen) should be controlled and to what degree. (The determination is beyond the scope of this paper, but has been outlined by others.[6]) The limits chosen for motor-vehicle exhausts were 1·5% for the carbon monoxide content and 275

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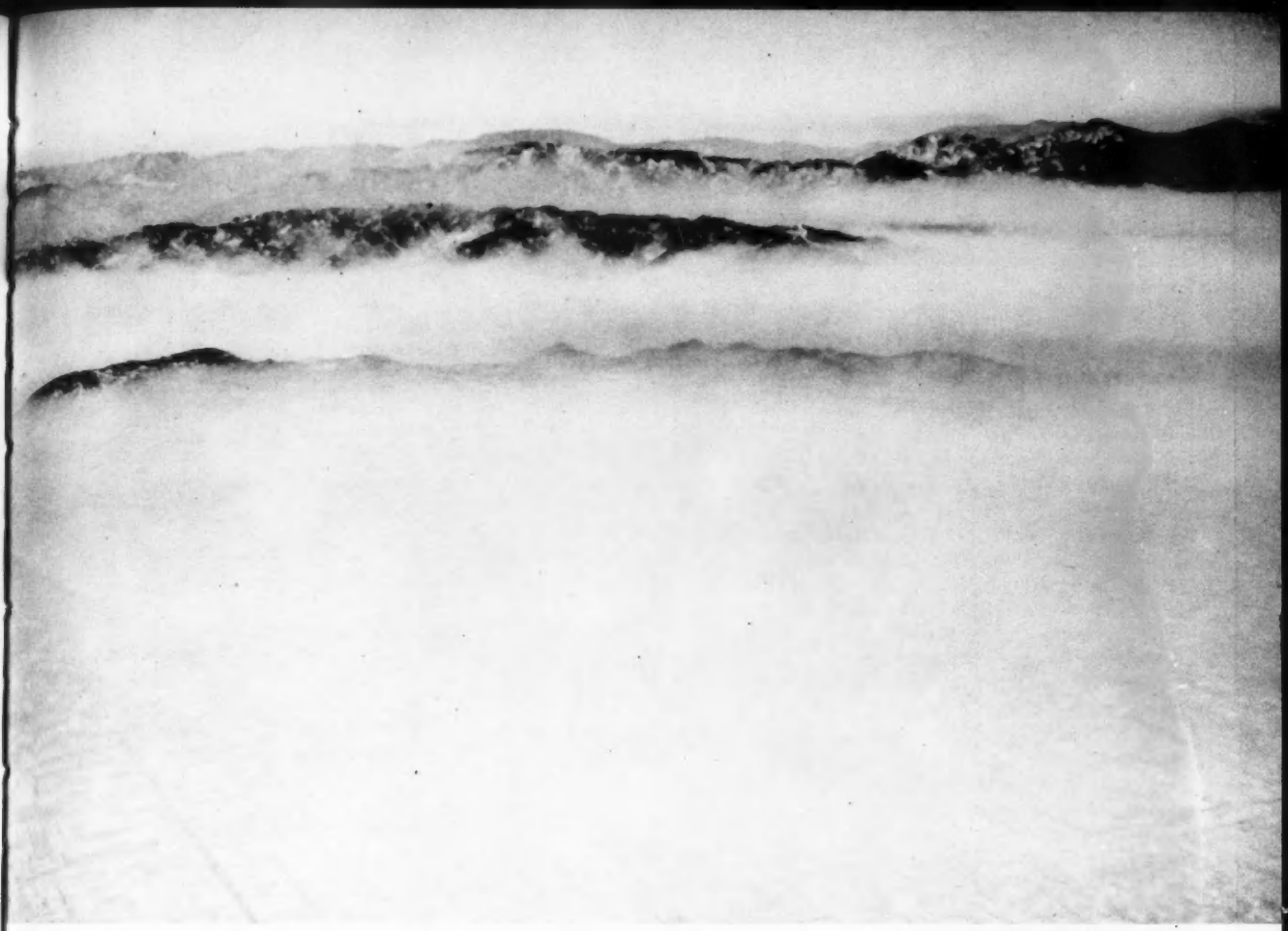


(*Associated Press*)

FIG. 1. The 1600-sq.-mile Los Angeles basin in Southern California is surrounded on three sides by high mountains and on the west by the Pacific Ocean, from whence flows the prevailing winds. Late summer and early autumn bring conditions that are conducive to the development of smog: calm air, intense sunlight and a temperature inversion. Pollutants accumulate in this stagnant air régime until they are either blown away or the temperature inversion is broken.

p.p.m. for total hydrocarbons.* Basically, these values represent a 60% reduction in carbon monoxide and an 80% reduction in total hydrocarbons from the average Los Angeles automobile which emits gases containing 3·8% carbon monoxide and 1375 p.p.m. hydrocarbons when operated over the integrated cycle mentioned in the footnote.

THE CALIFORNIA MOTOR VEHICLE POLLUTION CONTROL LAW

Under the impetus of approved State standards for exhaust contaminants, the State Legislature early in 1960 passed an act aimed at mandatory control of motor-vehicle exhaust emissions.

* These values refer to the concentrations of the two materials in the exhaust gases of any motor vehicle operated over a designated cycle that represents average driving conditions in Los Angeles.

The act sets up a thirteen-man Motor Vehicle Pollution Control Board (appointed by the Governor) which is empowered to establish criteria for approval of control devices, arrange for device testing, and certify at least two such devices for sale in California. One year after two devices or more have been approved, every new motor vehicle sold in California must be equipped with one of them before it can be licensed. All used motor vehicles undergoing a change of ownership must also be so equipped, unless the authorities in a given county declare no air-pollution problem exists there. The purpose of the escape clause was to exempt owners of old cars who reside in sparsely settled mountain counties.

All commercial vehicles must be suitably equipped after the second year, and all remaining cars except those in exempt counties after the third year.

DEVELOPMENT OF EXHAUST-CONTROL DEVICES

Prior to actual passage of the control act, considerable research and development activity on exhaust-control devices had been sparked by the imminence of control laws and the goodly size of the market.

California is one of the world's most motorised areas. Seven million motor vehicles are licensed for operation in the State, and new car sales are about 700,000 motor vehicles annually. An estimate of the rate of market development[3] is summarised below.

Prior to the establishment of exhaust

Table I

Years after Certification	New Vehicles	Used Vehicles	Total
1–2	600,000	1,200,000	1,800,000
2–3	630,000	1,700,000	2,330,000
3–4	660,000	2,500,000	3,160,000

standards, many organisations were working on carburettor fuel cut-off devices and other deceleration control units[2] that would reduce the emission of hydrocarbons. The establishment of a limit for carbon monoxide brought a halt to this work, for the only known way of reducing the amount of CO in the exhaust is by improving the combustion in the engine or by adding an afterburner. This development made the addition of an afterburner practically mandatory, for the design of internal combustion engines at present (with insufficient air for complete combustion) makes it practically impossible to completely eliminate carbon monoxide (and hydrocarbons as well) from the exhaust gases.

Furthermore, the wide variations in air and fuel flow rates and engine speed during normal operation, and the necessity to change vehicle manoeuvres rapidly, result in loss of efficiency and increased emissions over those from a stationary engine. Typical engine variations, exhaust flows, and exhaust contaminant concentrations are shown in Table II.

DEVELOPMENT OF AFTERBURNERS

Since incomplete combustion produces major exhaust contaminants (carbon monoxide and hydrocarbons) and there is little likelihood of increasing burning efficiency in the automobile engine, one must resort to burning the combustibles after they leave the engine cylinders and before they reach the atmosphere via the tailpipe. Thus we have need for an efficient afterburner.

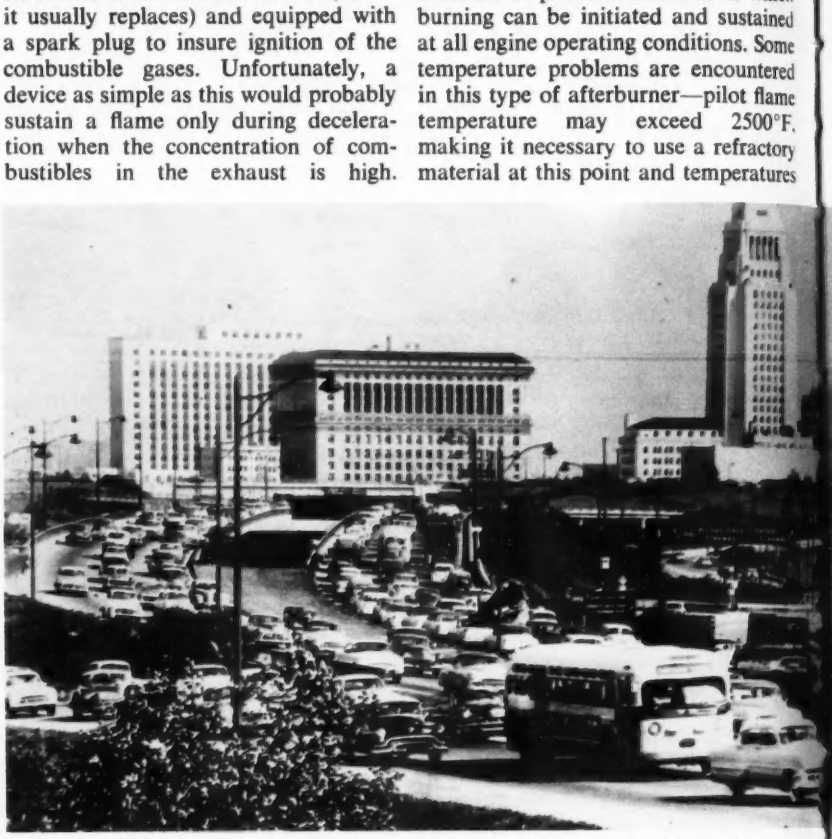
The function of an afterburner, of course, is to complete the combustion process initiated in the engine. Generally, this requires the addition of more air and the maintenance of a temperature-concentration-time relationship that will insure ignition and burning; the problem is complicated by the wide variation in exhaust parameters. One must also arrange to remove heat from the burning exhaust if the temperature reaches the point where it may damage the afterburner structure.

Two basic approaches have been utilised by developers—the *direct-flame* afterburner and the *catalytic* afterburner.

DIRECT-FLAME AFTERBURNERS

The direct-flame afterburner is primarily a combustion chamber about the same size as the exhaust muffler (which it usually replaces) and equipped with a spark plug to insure ignition of the combustible gases. Unfortunately, a device as simple as this would probably sustain a flame only during deceleration when the concentration of combustibles in the exhaust is high. Continual burning is usually achieved by two means.

A. In one, raw gasoline is supplied directly to a pilot burner in the chamber to produce mixtures in which burning can be initiated and sustained at all engine operating conditions. Some temperature problems are encountered in this type of afterburner—pilot flame temperature may exceed 2500°F, making it necessary to use a refractory material at this point and temperatures



(Associated Press)

FIG. 2. Six million persons in the Los Angeles basin own and operate 3 million motor vehicles which daily send 7000 million cu. ft. of exhaust gases into the air. Photograph above was taken at the start of a period of smog.

Table II. Effect of Engine Operating Conditions on Composition of Auto Exhaust

	Idle	Acceleration	Cruising	Deceleration
Air-fuel ratio	11:1–12·5:1	11:1–13:1	13:1–15:1	11:1–12·5:1
Engine speed (r.p.m.)	400–500	400–3000	1000–3000	3000–400
Airflow (c.f.m.)	6–8	30–35	15–35	6–8
Cylinder vacuum (in. Hg)	16–20	0–7	7–19	20–25
Exhaust gas temp. (°F)	300–400	1000–1100	600–700	400–900
Exhaust analysis:				
CO (%)	4–6	0–6	1–4	2–4
NO (p.p.m.)	10–50	1000–4000	1000–3000	10–50
Hydrocarbons (p.p.m.)	500–1000	50–500	200–300	4000–12000
Unburned fuel (% of supplied fuel)	4–6	2–4	2–4	20–60

r.p.m.—revolutions per minute
p.p.m.—parts per million, by volume
c.f.m.—cubic feet per minute
in. Hg—vacuum, inches of mercury
CO—carbon monoxide
NO—nitric oxide

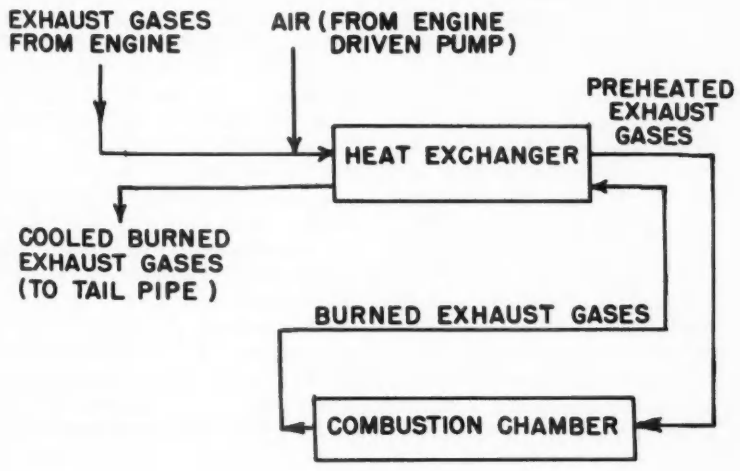
up to 3000°F may be reached in the afterburner during deceleration requiring the use of exotic materials in the afterburner housing. Such materials are expensive.

Two approaches have been utilised to avoid these high temperatures. In one design, a fuel cut-off valve at the carburettor is actuated when the car is decelerated (and the addition of fuel is not required) thereby preventing high concentrations of hydrocarbons in the afterburner during this period. This design also includes a temperature-controlled valve to bypass the exhaust gases around the afterburner when their temperature becomes excessive during prolonged cruising at high speeds. Obviously, all of these protective devices cost money and increase total cost of the afterburner.

A more sophisticated approach to the dual problem of maintaining combustion in the afterburner and removing excess heat is shown in Fig. 4. In this scheme, some of the heat in the burned exhaust gases coming from the afterburner combustion chamber is transferred to the incoming air and gas by means of a heat exchanger. The former are thus cooled while the latter are heated to the point where combustion can be effected. The heat exchanger, usually a bundle of tubes, increases the cost however, and replacement may be required at intervals if thin tubing is used.

FIG. 3 (*above*). Los Angeles during its sixteenth successive day of severe smog last October.

FIG. 4 (*below*). Schematic diagram of a direct-flame afterburner.



B. A slightly different approach is embodied in an afterburner development model produced by Thompson Ramo Wooldridge, Inc. (Fig. 5). In this unit, designed for installation as near the exhaust manifold as possible, the combustion chamber is flanked on both sides by two ceramic heat accumulators. The hot gases coming from the afterburner combustion chamber are passed through one heat accumulator until a specific temperature is reached and then, by means of a magnetic reversing valve, switched to the second heat accumulator. Simultaneously, the exhaust from the engine is directed into the first heat accumulator where it is preheated before going into the afterburner combustion chamber. By switching back and forth, the afterburner exhaust is continually cooled, while the incoming mixture is heated.

CATALYTIC AFTERBURNERS

In catalytic afterburners an oxidation catalyst is used to initiate and sustain at a lower energy (temperature) level than in the direct-flame afterburner. Here the reduced cost of the afterburner housing must be balanced against the cost of the catalyst which must be replaced at specified intervals, its activity decreasing with time due to a temperature effect and the various additives and impurities in the gasoline.

One such device, shown in Fig. 6, was presented to the California Motor Vehicle Pollution Control Board recently for testing. The manufacturer claims the unit will have a two-year life under California conditions and can be replaced every two years at a lower overall cost than an afterburner designed to last indefinitely, because of the low-cost materials used.

Another catalytic afterburner is shown in Fig. 7.

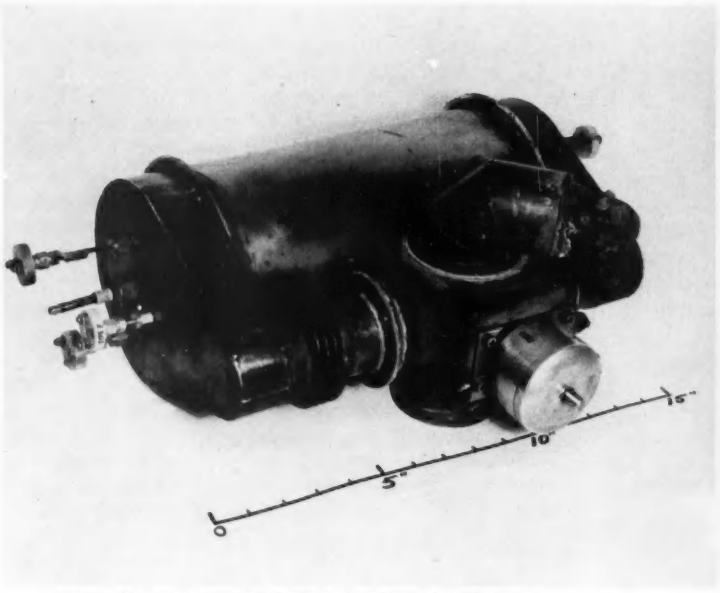


FIG. 5. Direct-flame afterburner developed by Thompson Ramo Wooldridge (U.S.A.).

FIG. 6. Catalytic afterburner of the Universal Oxidation Processes Co. (U.S.A.).

CRITERIA FOR APPROVAL

Only a few afterburners have been presented to the Board for certification testing to date; most companies are deferring their applications until the Board publishes a complete set of specifications or criteria. The only requirements at present are the carbon monoxide and hydrocarbon limitations set by the State Board of Health. The Motor Vehicle Pollution Control Board has indicated, however, that other criteria presently under study will need to be met before any device is certified. These may include testing for public safety (fire, explosion, etc.), obnoxious odour, excessive noise, service life, resistance to backfire, resistance to splashing, compatibility with engine back-pressure and auto design (for example, road clearance), and cost. Current opinion indicates that cost will be calculated as cost per mile over the useful life of the afterburner and will include original cost, installation and maintenance, added fuel, all accessories (air pump, bypass, etc.), and inspection requirements. The figure of 0·5 cents per mile has been bandied about.

IS CALIFORNIA SERIOUS?

One of the questions I am asked most frequently, particularly by Europeans, is the following: Are Californians really serious? Do they expect to require afterburners on all motor vehicles in the State? Or is the law mainly one to pressure automobile manufacturers into improving the automotive power plant?

First, there must be no doubt that this is a serious law, even though there was a great deal of speculation about the probable cost of a suitable device before the law was enacted and no responsible person backed the legislation with predictions of low cost. As to the alternative possibility of an improvement in engines to the point where devices might not be necessary—no one believes this is imminent. It is a praiseworthy goal and highly desirable, but it must be at least fifteen years away as far as general usage is concerned.

The fact that many persons question the sincerity of the law must mean they are either confused by items they have read in the Press or are being led astray be the actions and pronouncements of government officials and industrial leaders, even if inadvertently. Four items contribute to the confusion: crankcase blowby control, gasoline composition, diesel emissions, and the fear of lung cancer.

Crankcase blowby control. About the time the motor vehicle control law was enacted, the automobile manufacturers released some figures[1] that indicated the hydrocarbon problem in Los Angeles was not entirely due to exhaust gases—that under some conditions the quantity of hydrocarbons escaping from the crankcase via the blowby breather pipe equalled that in the engine exhaust. Studies by others[5, 6] subsequently put the hydrocarbons in the crankcase blowby at one-fourth to one-third of the total. Control of the crankcase blowby has proved to be comparatively inexpensive, ranging from $1 to $10 per car (7*s*. to 71*s*.) for a control device. The County of Los Angeles consequently installed such devices on all County-owned vehicles. In addition, blowby controls (in which crankcase vapours are passed into the engine to be burned) were voluntarily made a standard item for all new American-made automobiles sold in California. The State Department of Public Health set a blowby emission standard (0·15% of supplied fuel under specified operation conditions) and the Control Board later indicated that blowby control must be incorporated into an exhaust control device either by returning the blowby directly to the intake manifold of the engine or directly to the afterburner. During the early stages of this particular development, when the Press reported that an "automobile smog controller" was available for less than $10 the public began to wonder about the need for

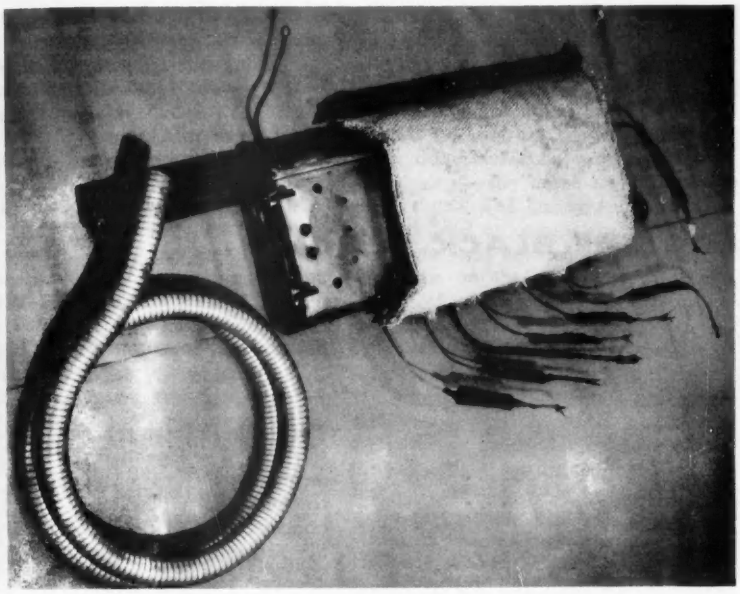


FIG. 7. Catalytic afterburner developed by the Wolverine Tube Division of Calumet & Hecla, Inc. (U.S.A.).

costly afterburners, but the confusion is beginning to lift.

Control of Gasoline Composition. Before the Motor Vehicle Pollution Control Act was passed, the Board of Supervisors of Los Angeles County passed a rule regulating the olefin content of gasoline sold in the County. Even though most scientists acquainted with the problem thought the so-called "research" upon which the law was based was spurious, political expedience dictated this action. (There is a small, but noisy, anti-petroleum-industry group in Los Angeles.) Subsequent research at the U.S. Bureau of Mines[4] showed the regulation is not technically sound. Although the law was designed to go into effect in two steps, the first of which was more or less innocuous, the second step will probably never be activated. The noisy minority is still complaining about "dirty" gasoline, however.

The Diesel Problem. Another source of genuine confusion is the widely noticed black-smoke plume and obnoxious odour often associated with the exhaust from diesel-powered trucks and buses. Even when one is assured that diesel exhaust is almost singularly free of carbon monoxide and olefinic hydrocarbons, most people find it difficult to believe that what they see and smell isn't a great deal more harmful than invisible, almost odourless gases.

Fear of Lung Cancer. The great rise in lung cancer incidence in urban communities has led to considerable speculation on its cause. In as much as both lung cancer and air pollution appear to increase with increased urbanisation, it would be unusual if someone did not infer that a cause-and-effect relationship existed between the two. When it is also pointed out that automobile population has its greatest density in large communities, a causal relationship is again suggested. The result is a form of hysteria among some segments of the population, the irrationality of which endangers a sound approach to automobile exhaust control.

COMMUNITIES OUTSIDE CALIFORNIA

There is no doubt that the California crusade to control motor vehicle exhaust has stimulated similar action all over the world. Such stimulation, at least to examine the problem, is praiseworthy, but in too many communities stimulation does not lead to a rational examination of the problem. There is, rather, a tendency to conclude that if motor vehicle exhaust control will cure the highly publicised Los Angeles smog, it will cure any problem, anywhere.

What, then, is the correct procedure? Proper action falls into several categories. Any community with a photochemical smog problem would do well to assess the contaminants in the atmosphere, determine the emissions from the local automobile population, and calculate how much reduction is necessary. If the problem is only one of photochemical smog, only hydrocarbon reduction may be necessary. In most Eastern U.S. cities, one will find that simple blowby control may be adequate for many years.

If the problem is carbon monoxide, an afterburner may be required, but one should not blindly accept the ambient air standards devised for California. Many believe the standards need more study. If the problem is neither hydrocarbons nor carbon monoxide, it would be well to check stationary sources and not worry about motor vehicles. If one's concern is for the general health of the public, we should help our medical and biological research teams find adequate research funds to delineate the problem.

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THE BOOKSHELF

THE WHITE KNIGHT AND THE BLACK BARON . . .

SIR ROBERT WATSON-WATT

Science and Government

By C. P. Snow (*Oxford University Press, 72 pp., 7s. 6d.*)

The lecturer chosen for the Godham Lectures on "The Essentials of Free Government and the Duties of the Citizen" should recognise the responsibility as well as the honour conveyed by Harvard's invitation. My former colleague and present friend, Sir Charles Snow, has not, in my view, lived up to the promise of the title "Science and Government". Whether the dirty linen of Science in Government should have been washed in the "wrong" Cambridge is a minor matter of taste. That it should have been lightly attempted by a distinguished writer of fiction and drama is highly debatable. But it should have been done thoroughly and responsibly with careful scrutiny of the available and relatively copious evidence. This, one would suppose, was an obvious duty. Having selected his Knight in shining Armour (Sir Henry Tizard), he should have noted that he became a knight after Act I had ended—the accolade was of 1937, not of pre-1934 as indicated in the programme. The dark and sinister Baron (Frederick Lindemann, or Lord Cherwell) was far more despicable than any *real* Englishman could ever be. There was no room on stage, beyond a mere walking-on part for the Scot, for the Celtic fringe.

I recognise my long-term friends, colleagues and benefactors, Tizard and Lindemann, neither in the snow-white hero nor in the Abominable Snow Man of these lectures. Let us condescend to the facts, as the lawyers usually urge.

The facts include the shattering failure of the defence in an Air Exercise of 1934, which caused the Air Officer Commanding-in-Chief to beg for aid from two scientists —Wimperis and Tizard. The facts also include a very English action—that of writing to *The Times*—by the "quite un-English" and villainous Lindemann, a letter asking for a new look at science in air defence. Un-Englishness was carried to an extreme when Winston Churchill and Lindemann were so unmannerly as

to hammer on the door of the Prime Minister's summer retreat at Aix-les-Bains demanding more satisfaction than had been accorded in the House—again in relation to science in air defence.

But how did the A.S.M. reach intimate and enduring friendship with the man who was to be the very symbol of Englishness in his stubborn refusal to accept military defeat? How very English was the occasion. Another Frederick, the first Lord Birkenhead, asked the American-born captain of the Oxford tennis team to bring a tennis six to his country house for a week-end. The six included Frederick Lindemann who "may have been a German or an Alsatian", and thus began, in 1922, a very close and enduring friendship with another guest, Winston Churchill. All these threads belong to the pattern of Act I of the duel between the good man and the bad man. So does A. P. Rowe's discovery of no more than fifty-three files bearing on Air Defence among the thousands of files in the Air Ministry.

Wimperis had been appointed Director of Scientific Research of the Air Ministry on the advice of Tizard, when Tizard himself refused the post for which he was recommended.

Now the threads converge; Wimperis recommended the setting up of a new committee for the scientific survey of Air Defence, with Tizard as chairman and with terms of reference which C. P. Snow chooses to regard as flat. That the flatness blew up was the doing of Wimperis. He invited me—an obscure Scot who had been doing obscure work on radio-meteorology—to "come up and see me some time". The consequent visit, carefully defined as completely unofficial on both sides, was devoted to questioning by Wimperis on the possibility of using a beam of damaging radiation against hostile aircraft. My answer was hostile to death rays but was qualified by a promise to do some arithmetic. The resulting memorandum dismissed death rays and ended with an unsolicited promise: "Meanwhile, attention is being turned to the still difficult but less unpromising problem of radio-detection as opposed to radio-destruction, and numerical considerations on the method of detection by reflected waves will be submitted when required."

The prior document was reported to the CSSAD *at its first meeting* on January 28, 1935. The second document was, in effect, a detailed quantitative appreciation and specification for a coherent system of air defence by what was later to be called radar, but it went well beyond mere detection or location, emphasising the need for identification of friend from foe, for exceptionally good radiotelephone communication to the fighter pilot in person, and so on. The scheme was wholly mine although the computation was done with A. F. Wilkins. The first draft was dated February 12 and the "definitive version" was before the CSSAD at its second meeting on February 27, 1935.

This story is economically mishandled by default in C.P.'s melodrama, for he says: "The committee made up its mind about [backing radar] before the device really existed [True]. Watson Watt, who was the pioneer of radar in England working in the Radio Research Laboratory of the DSIR had done some preliminary experiments [False]. . . . Tizard Hill, Blackett had faith in their own reasoning [True, if he will admit that they had swallowed my reasoning whole]. All that was left for them to do was to re-check the arithmetic, which could be wrong by a factor of ten without this being fatal to the scheme."

"Without fuss, and without backward glances, the choice was made. That was only a resolution on paper, and they had to make it actual." It is usually easy to choose between something and nothing!

C.P. tells of Lindemann's appointment

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to the Committee but he does not note the critical date, about July 8, 1935. "Radar was not yet proved to work . . . arrangements well in advance even of the first tests, for its operational use. It was in fact in the operational use of radar, rather than in the equipment, that England got a slight tactical lead." The "slight" tactical lead extended far beyond Pearl Harbour, and years beyond effective German use—as is very handsomely recorded by the U.S. and Germany alike.

Now for the Prof. There is no evidence known to me that Lindemann thought that the "non-competitive priority" given to less than ten men, scientists, assistants and labourers, was too high. Their work drew no one from any project favoured by him. But this is somewhat negative evidence; what is the positive? On June 12, 1936 Lindemann brought me an invitation to have tea with Winston Churchill that day. They wanted to know whether Air Ministry was acting as speedily towards radar development as I thought necessary and attainable. I said that I was dissatisfied with the policy which attempted to operate the normal Ministry machinery at an abnormal speed instead of setting up new machinery designed for a normal speed greatly exceeding that which existed. In an only partially light-hearted moment —though it was not I who had brandy in lieu of tea—I remarked that this was Friday the thirteenth. Since Friday, March 13 was the day on which a CSSAD recommendation had been made I should be given authority to improve the communications systems which were indispensable elements in the radar system as a whole. Three weeks had passed since I receded by a third step from the requirements which I knew to be improvements. And so on.

I have not sought access to papers which have the sacred status of Cabinet documents, but I have very good reason indeed for believing that the resignation of "the Prof." from CSSAD was based on his views on these matters—matters on which Churchill, Lindemann and I were openly, and Tizard more discreetly, expressing the gravest dissatisfaction. If C.P. has "done his homework" on this crisis I trust that he will state his view of facts and consequences equally clearly.

I need not catalogue other examples of the lack of proof or probability in statements by C.P. about the radar programme which moved forward with unparallelled speed; much more could have been achieved had this part of science in government been de-departmentalised.

Act II is even more easily dismissed than is Act I. I cannot concur in Patrick Blackett's summary rejection of the commonly used argument "What else could we have done?" in his discussion of the relative unselective bombing programme. I can, however, state with absolute certainty that Lindemann did far more than did any of those who were in control of bombing policy to ensure the success of whatever policy was to be followed. In particular, it was he who demanded of us a radar-type aid to precise target-finding in poor visibility—an aid not depending on vulnerable ground signals which could be drowned or made misleading by the enemy. It was he who brought convincing proof, through a survey of 700 photographs made at the moment when the aircrew believed they had located and successfully bombed their allotted target, that these claims were fantastically optimistic, though honestly believed. His pressure on me, and on my colleagues in the then very large teams at our Telecommunications Research Establishment was more burdensome but vastly more welcome than the curt dismissal in "Bert's" historic message "Tell TRE to mind its own bloody business". This is precisely what Lindemann fought for, but the conceptions of our adjectival business were vastly different. For me, the Prof. was a vigorous and agreeable slave-

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driver, for whom we worked hard and from whom we had reasoned advice, reasoned demands, and encouraging appreciation in both Acts I and II of the radar drama.

Biochemistry of Insects

By Darcy Gilmour (*Academic Press, 1960, 343 pp., 64s.*)

There can be few scientific subjects which have shown such a dramatic growth in recent years as that of the biochemistry of insects. Despite some early pioneering work the subject scarcely existed ten years ago. Today, due to an ever-increasing volume of research, insect biochemistry stands as a clearly defined part of our biological knowledge. The appearance of Dr Darcy Gilmour's book, the first text in the field, is therefore of some importance.

In most textbooks of biochemistry and in review articles, the various biochemical principles described are often based on data derived from widely differing organisms. Such a wide approach has, of course, been exceedingly valuable and has led, by implication, to the concept of the unity of biochemistry. However, as the author points out in his preface, this approach to biochemistry has tended to emphasise the elucidation of chemical reactions without relating them to the structural and physiological organisation of the particular animals studied. The present textbook is, therefore, to be welcomed in its attempt to explain biochemical principles in relation to the structure and peculiarities of a particular animal group, especially as in this case the insects comprise about three-quarters of the known animal species.

The information contained in this book is grouped into three main sections: energy metabolism, intermediate metabolism, and the biochemistry of development. In the first of these sections, the various processes involved in insect nutrition and digestion are discussed, together with an account of anaerobic and aerobic energy production. The usages of the energy derived from these oxidative processes are described and in another chapter a very clear account is given of the various end-products of catabolism. In the section on intermediate metabolism the author deals with metabolic processes other than those associated with the release and expenditure of energy. These chapters are concerned with the synthesis of the various cellular components and of the special secretions of the insect body. The final section of this book is a very brief account of our knowledge of the biochemistry of hormones and morphogenesis in insects.

In the preface, Dr Gilmour says that he has aimed at a complete coverage of the existing knowledge of insect biochemistry. Such an aim is, of course, almost impossible to attain in practice and there are in fact several omissions in the chapters on nutrition and digestion and in the pages dealing with the composition of the haemolymph. Such omissions are, however, a small price to pay for such an excellent critical analysis. A study such as this could well have emerged merely as a formidable and unreadable factual catalogue. This book is a well written and eminently readable account of this very important subject.

J. E. TREHERNE

Department of Zoology, University of Cambridge

Atomic Energy Waste: Its Nature, Use and Disposal

Edited by E. Glueckauf (*Butterworths, 420 pp., 95s.*)

The disposal of radioactive waste is one of the major problems associated with nuclear power, and one which has no parallel in other fields. While there are many similarities between the handling of radioactive substances and the more dangerous bacterial agents, the latter can be made innocuous by chemical means or by heat, whereas the former, though constantly decreasing in strength, may remain active for very long times and cannot be destroyed by any known method.

The uses of radioactive substances are increasing almost daily, so it is important that literature on the subject should be readily available. Other than scientific papers on various specialist branches of the subject, we have already, in Great Britain, two textbooks; the first by Saddington and Templeton, concentrates on the general principles of disposal and is a good general introduction to the subject; the second, edited by Collins, again concentrates on principles, but includes some useful information on the nature and measurement of radioactivity, together with an excellent chapter on Health Physics.

The new work, edited by Glueckauf is, however, in a slightly different category. It is much larger and more detailed, and includes chapters on current and potential uses of large quantities of radioactive material in agriculture, food preservation, and industrial chemistry. Nineteen authors have contributed to it; eighteen are in senior positions at the Harwell, Windscale, or Wantage establishments

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of the United Kingdom Atomic Energy Authority, and one is at the Radiobiological Laboratory of the Agricultural Research Council. All, needless to say, are well known in their respective fields.

The title is, perhaps, a little misleading, though it does accurately describe the latter half of the book. The first half is rather more general, providing an excellent background to the subject.

The fission process is treated in considerable detail in the first chapter, which includes several comprehensive tables giving fission product decay chains for U^{235}, the quantities of individual elements formed by fission of 100 gm. of U^{235} (for an irradiation time of 150 days and a cooling time of 30 days), and the nuclear properties of U^{235} fission products, as well as a number of useful graphs. Some criticism may, however, be levelled at one such series, which gives the elemental composition of fission product beta-activity as a function of cooling time, for three neutron fluxes and seven irradiation times. Too much information has been included for the scale of reproduction of these graphs, with the result that the reader is confused by the maze of lines, apparently running in all directions; this type of graph is most valuable when on a large scale, but even then the use of different colours is a tremendous aid to interpretation.

The effects of radiation on materials and living organisms are well treated; the chapter on radiation chemistry is a good general review of the present position and is well supplemented by almost a hundred references. There are two chapters on biology: the effects of radiation on living cells, and the movement of radioactive substances in food chains; both of these are well written and should be readily intelligible to the non-biologist. The sections on radiation protection and legal aspects, though short, are first-class reviews of the present position, referring to international as well as British practice.

It is an interesting point, that of the 420 pages in the book, only 143 are devoted to the treatment of radioactive wastes. However, the subject is adequately covered, both on the low-activity side where possible methods and large-scale practice are discussed, and on the high-activity side where, as on the low-activity side, British, Canadian and American practices are considered. A particularly interesting section deals with possible methods of converting highly active wastes to solid products, a line of approach which is being investigated extensively at the present time since it will eliminate the difficult and costly storage of highly active liquors. Factors restricting the discharge of gaseous waste to the atmosphere are briefly discussed with particular reference to meteorological conditions. The final chapters, constituting about sixty pages, cover actual and potential uses of fission products, mainly in the form of large sources of radiation, principally for food preservation and the induction of certain chemical reactions. A good selection of references is provided throughout.

Summarising, it can be said that the book is an interesting addition to existing publications, but is rather unbalanced if one takes the title at its face value, since only about half of the book is devoted strictly to nuclear wastes. The first half is, however, a valuable section in its own right and might well be overlooked under the present title. The price, needless to say, is rather forbidding and will probably exclude the book from many personal bookshelves, though it should certainly be included in libraries covering radiochemistry and nuclear chemical engineering.

H. D. EVANS

Chemical Engineering Department, Imperial College, London

Annual Review of Nuclear Science, Vol. 10, 1960

By Emilio Segre (*Annual Reviews, Inc., Palo Alto, California, 607 pp., $7.00*)

This annual review has long had an excellent reputation as a source of information for physicists and this tenth volume provides an unusually nourishing diet. About half of it is devoted to nuclear physics proper; the rest covers subjects such as cosmic rays, chemistry, geology and biology. The first article by F. Reines describes his own work through which the neutrino after decades of futile attempts has at last been made detectable. It shows the massive and well-planned efforts that were needed for this and describes in unemotional tones the exciting possibilities which are opened up thereby and the many questions which still remain to be answered.

Cosmic rays are covered twice. In the first place Greisen gives a masterly survey of those big showers of electrons (up to many millions at a time) which are caused in the atmosphere by the entry of single particles of very high energy. He gives a brief but very comprehensive discussion of the cosmological significance of those studies, and an imaginative glimpse of the possibilities for future work. Later in the volume, a brief article by Ney skims lightly over a variety of work that was done during the IGY, including a discussion of the Van Allen radiation belt and of the Argus experi-

ment in which an artificial radiation belt was created temporarily by the explosion of an A-bomb over a hundred miles up.

The new wonder tool of high energy physics, the Bubble Chamber, is described by Bradner in a perfect little monograph of fifty pages. The history of the Bubble Chamber, its functioning, and many details of its operation are discussed with such clear diagrams that even minor instrumental details are well covered. The problem of analysing the photographs obtained is discussed concisely on three pages, including a brief description of those automatic measuring monsters which have been nicknamed "Franckenstein". A whole ancillary science of "beam handling" has grown up in the study of high energy particles, and the various methods of deflection and focusing are clearly described in Chamberlain's article, in useful detail. The physics of ordinary nuclei comes in twice; the theory of internal conversion of gamma rays is carefully covered in a rather mathematical article by Church and Weneser, and from Israel comes an admirable little monograph by Talmi and Unna on the theory of the energy levels of light nuclei, followed by a number of level diagrams compiled by that indispensable team, Fay Ajzenberg-Selove and Tom Lauritsen. Radioactive nuclei are often formed at high speed, recoiling as it were from whatever else is formed in the same process. In that state they are amenable to analysis by deflection and range measurements, and Harvey's article shows this to be a powerful tool for their identification and separation. The same recoil can also be used chemically for the forming of radioactively labelled compounds, as shown in Wolf's article. Perhaps most fundamental in the volume is the group of three articles on nucleon-nucleon scattering. The scope of this kind of study has been greatly increased by the use of polarised particles, and both the theory and a survey of the experimental data are given. The amount of work in this field is indicated by the fact that this article is followed by 254 references! One article by Beckerley deals with an industrial application: the geological investigation of bore holes. We learn that about 1% of the cost of drilling oil wells goes to their study by nuclear methods. That doesn't sound much but actually amounts to $25,000,000 per year.

The book ends with three articles on radiobiology: studies of the multifarious effects of radiation on single cells (Alper) are followed by the less academic question of the elimination of radioactive substances by vertebrates (of whom man is one!) and the even more sinister subject of delayed results of radiation such as genetic effects, induction of leukemia and general shortening of life. They remind us that nuclear science is important for us all.

O. R. FRISCH

Physics Department,
University of Cambridge

Electromagnetic Structure of Nucleons

By S. H. Drell and F. Zachariasen (*Oxford University Press, 109 pp., 12s. 6d.*)

Ever since the discovery of the electron, physicists have sought to interpret natural phenomena at short distances and high energies in terms of the properties of a number of fundamental particles. It was believed that a great simplification would be achieved when the nature and role of these particles was understood. In recent years it has been realised that not only is the number of such fundamental particles much greater than had been expected but that they are themselves very complex entities with a structure whose elucidation is providing fascinating problems both for the theoretical and experimental physicist; a simple structureless particle would indeed be an uninteresting object. The interest in these particles and, indeed,

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the possibility of studying them at all, arises from their interaction with other particles. These interactions, however, imply complicated structures and interrelationships among the fundamental particles.

The nucleons which constitute the nuclei of all matter cannot be thought of in isolation from all other kinds of fundamental particles. In field theory one sometimes uses the concept of the "bare nucleon", but it is a purely theoretical concept. Actual physical nucleons are always clothed in a cloud of other fundamental particles—mesons of various kinds, hyperons, anti-nucleons, photons, electrons, and so on. It is this cloud which determines the size of the nucleon and the determination of whose structure is discussed in this monograph.

Since many of the particles in the cloud are charged, a great deal can be done to investigate its structure by studying the interaction of nucleons with beams of charged particles. It is this aspect of the study of nucleon structure which has been most extensively pursued in recent years and which is described in the present book. The use of π-mesons and other strongly interacting particles as probes of nuclear structure is in a much earlier stage but is certain eventually to prove a powerful tool in such investigations.

The present monograph is written at a comparatively advanced level and will be of most use to specialists or research students in high-energy physics. It assumes a good knowledge of quantum field theory, but for those who can appreciate it, it is written with great clarity and in an absorbingly interesting style. After a chapter defining the various form factors which are used to specify the electromagnetic structure of nucleons, the second chapter gives an account of the method of deducing such form factors from experiment, including a very lucid exposition of the application of the new art of pology. The third chapter discusses at some length the various, and so far not very successful attempts, to calculate form factors theoretically. In the final chapter a question of great current interest—the validity of quantum electrodynamics at short distances and high energies—is discussed in relation to the experimental determination of nucleon form factors.

This monograph is one in the Oxford Library of the Physical Sciences. Although this series has been started comparatively recently it has already established a high reputation for topicality of choice of title and lucidity of exposition. The present work will enhance this reputation. The following monograph is also one in the Oxford Library of the Physical Sciences, but it is written at a different level and for a different group of readers.

The Fundamental Atomic Constants

By J. H. Sanders (*Oxford University Press, 88 pp., 10s.*)

This book contains clearly written accounts of the direct measurement of the electronic charge e, Avogadro's number N, the Faraday, the specific charge of the electron e/m, the ratio h/e and the Rydberg constant, while a whole chapter is devoted to a discussion of the measurement of the velocity of light.

It has become the practice recently to establish the "best" values of the fundamental constants by using measurements which can be carried out with great accuracy and in the interpretation of which various combinations of these constants occur. Following the work of Cohen and du Mond, the measurements which are used are the velocity of light, the mass of the proton, Rydberg's constant, the short wavelength limit of the continuous x-ray spectrum, the measurement of the magnetic moment of the proton in nuclear magnetons, the gyro-

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magnetic ratio of the proton, the fine structure separation in deuterium, the conversion factor from X-units to centimetres, the Faraday and the determination of Avogadro's number by the X-ray method. These experimental determinations are described in detail.

One thing that stands out clearly is the astonishing accuracy now obtainable in the measurement of frequency. It is this which largely accounts for the greatly improved accuracy with which fundamental constants are known now as compared with the pre-war position.

The monograph includes straightforward descriptions of experimental methods and results. A more critical analysis of the experiments would have improved it. Nevertheless, it should be useful to a wide circle of people, including undergraduates, research workers, and teachers of physics. E. H. S. BURHOP

Department of Physics,
University College, London

A Biology of Crustacea

By J. Green (*Witherby, 180 pp., 30s.*)

There is a great need at the present time for books which describe the general biology of particular groups of invertebrate animals, books which are published at a moderate price and are suitable for university students and others. They should not be aimed at the level of the invaluable but extremely expensive and rather formidable (to the student) tomes of Prof. Grassé's series or even the less costly volumes for which we are so much indebted to Prof. Hyman. The need is not really supplied by the various systematic monographs and "identification books", popular or otherwise—valuable and essential as these are. What is required, I think, is a return to the spirit of "The Cambridge Natural History", which is, so far as I can recall, the only comprehensive account of the Animal Kingdom completed in the last hundred years, with a peculiarly happy combination of anatomy, systematics, and natural history. It can be read with pleasure and ease by either student or the amateur, and will give him the necessary general background knowledge without the feeling, so important with regard to the former category, that he is being "instructed". In the present century there is a woeful scarcity of such books, although the Ray Society and Messrs Collins in their New Naturalist series have helped greatly to keep the flag flying.

The lack of books dealing with invertebrates other than insects is tremendous but one shining example is the late W. T. Calman's "The Life of the Crustacea". Although published in 1911, it is altogether admirable and it is a pity that there is only one passing reference to it in the book now under review.

We give, therefore, a warm welcome to Dr Green's present volume, which will be most valuable to university students and others who have at least an elementary acquaintance with the Crustacea. For those who have not, parts of the book may prove difficult. The first chapter, for example, which deals with "Origin and Radiation" is likely to form a stumbling block. As the author says, the satisfactory definition of the Crustacea as a whole is extremely difficult, but a greater effort to do this in terms of the living representatives of the group might have been made. Surely it would have been better to have started, as Calman does, with a very brief account of a familiar crustacean followed by a short survey of the classification of the group and then by a consideration of its origin and evolution. As it is, the uninitiated are confronted with a rather confusing assemblage of names and terms which are not always adequately explained.

The first chapter is the least satisfactory and its weakness may be due to overcompression but it should be expanded if a further edition is called for. The remainder of the book is very good and can be thoroughly recommended. The author is obviously well acquainted with the literature and has gathered information not merely from the obvious sources but also from the less known parts of the field. He deals, among other topics, with feeding, locomotion, blood, and colours and their changes. The chapters on growth and life histories, behaviour, the associations of Crustacea with other animals and parasitism are all clear, informative, and useful. The book ends with a good chapter on zoological distribution and a rather sketchy one on "Crustacea and Man". In this last, how is it that *Calanus finmarchicus*, in view of its great economic importance and the fact that we know more about it than almost any other crustacean, escaped notice?

The book is perhaps somewhat overloaded with examples of unfamiliar animals from many parts of the world. The black-and-white illustrations are clear but not always adequately labelled and explained.

This is, however, an excellent "background book" which can be strongly recommended and it should have a wide circulation. A. D. HOBSON

Department of Zoology,
King's College, Newcastle upon Tyne,
Durham University

PROGRESS OF SCIENCE

(*continued from page 229*)

The element 103 isotope is the first to be discovered solely by nuclear methods. No chemical techniques were used in its identification.

The new element was synthesised by bombarding a target consisting of three-millionths of a gram of californium (element 98) with boron-10 or boron-11 nuclei having energies of about 70 million electron volts.

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103 was made through a series of experiments which ruled out the possibility that isotopes of element 102 or element 101 might have produced the 8·6-MeV alpha particles. The half-life of the isotope of element 103 was determined to be about eight seconds.

The new isotope is thought by scientists to have a maximum atomic weight of 257, although further research will be required before this can be established conclusively.

The scientists pointed out that the actinide concept, elucidated by Glenn T. Seaborg (University of California), chairman of the U.S. Atomic Energy Commission, indicates that element 103 should be the last of the actinides to be discovered. The actinide series consists of fifteen elements with atomic numbers 89 through 103; they all have similar properties. Element 104 should have chemical properties different from those of all the transuranium elements that precede it.

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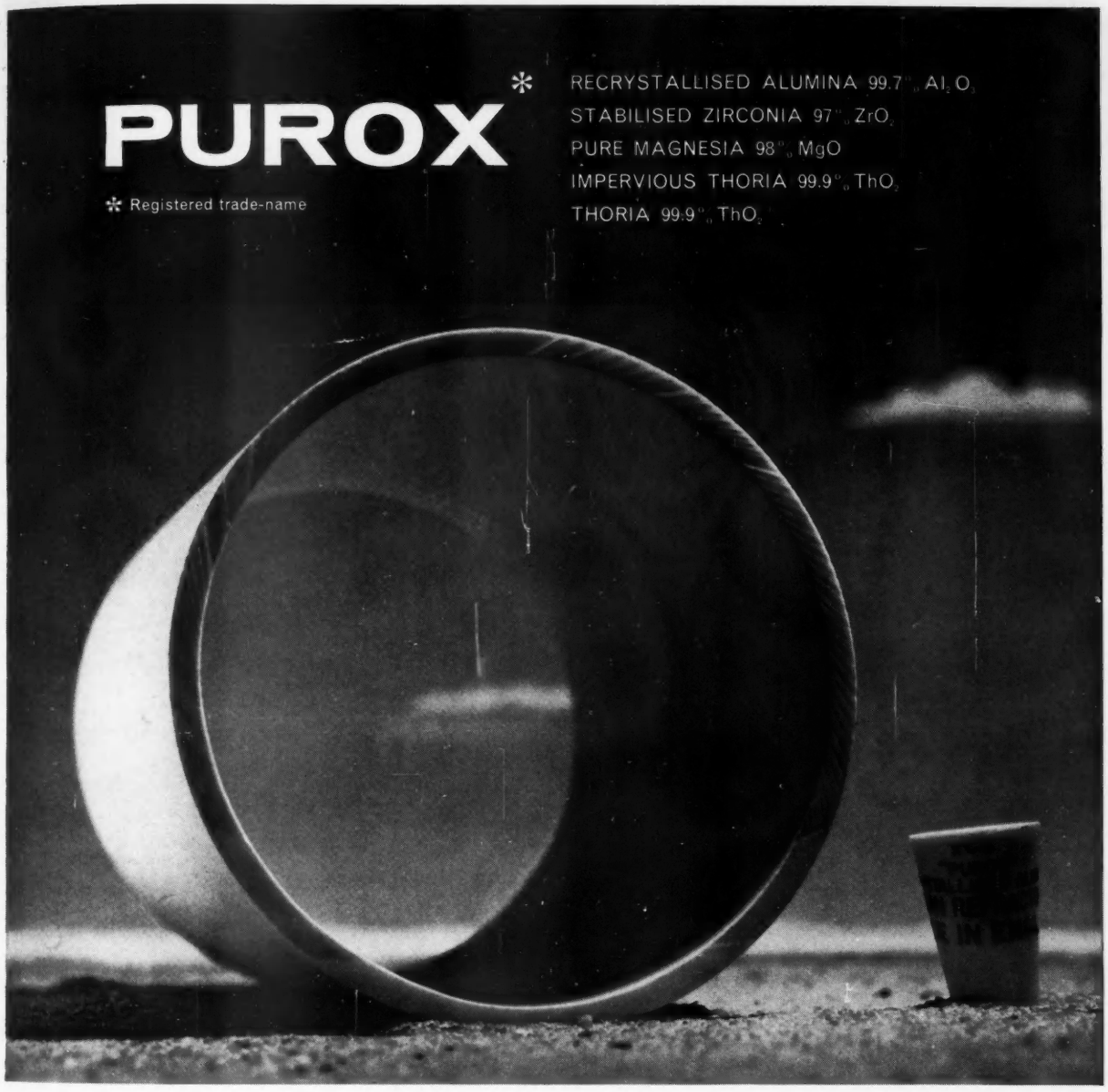

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